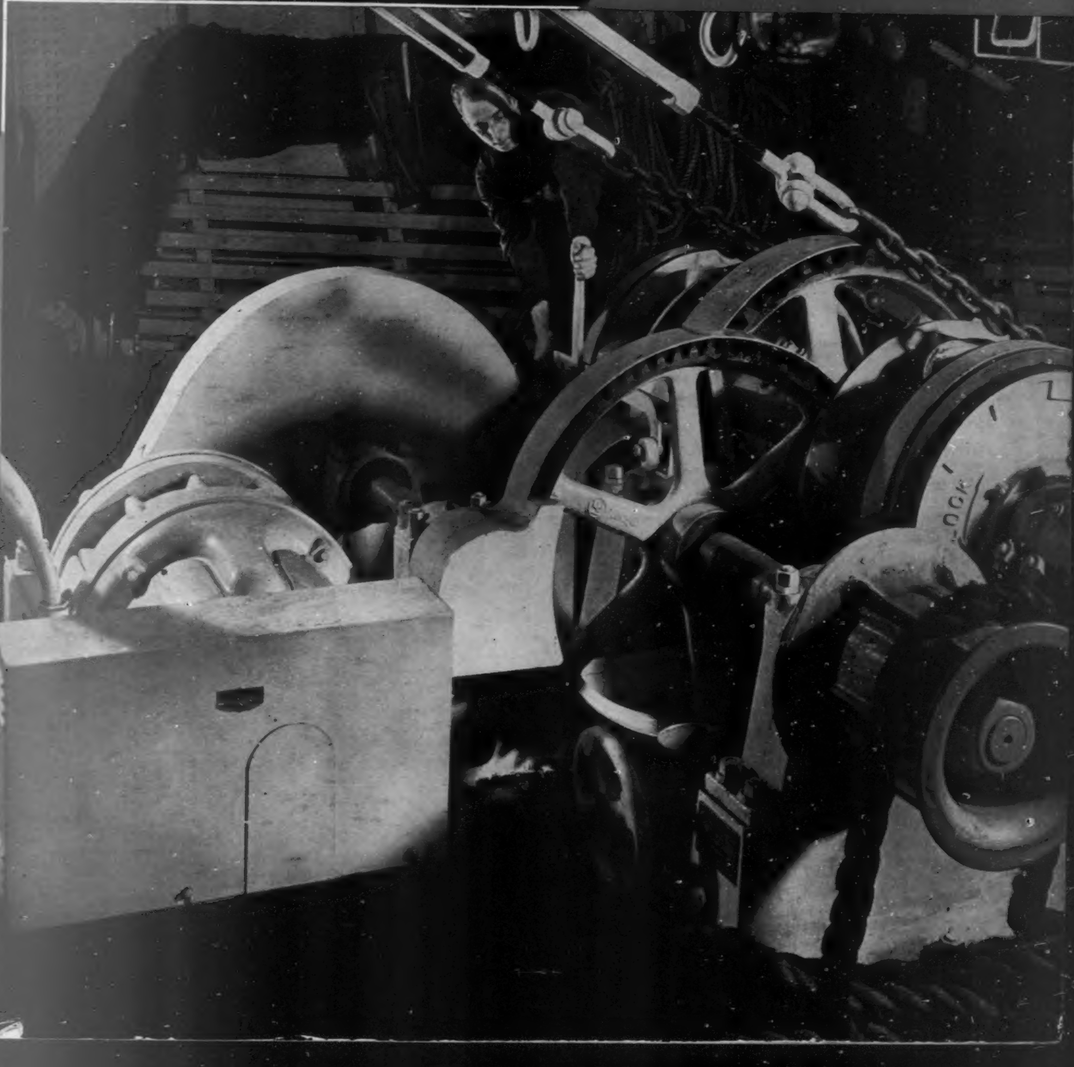
ALLIS-CHALMERS

ELECTRICAL REVIEW

S. R. Durand

December • 1941



Anchor windlass is powered by a 50 hp, 580 rpm, totally-enclosed wound rotor motor.

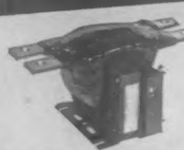
HIGHER ACCURACY

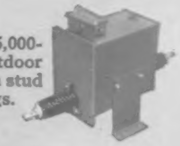
At LOWER Cost!

CURRENT TRANSFORMERS
FOR ACCURATE METERING


Type K — 5,000-15,000 volts, indoor, wound type.


Type BKWD—5,000-15,000 volts, outdoor bar type, compound filled, for metering or tripping.

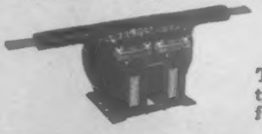

Type LDT—2500 volts, indoor wound type for metering of 3-wire circuits with one transformer.


Type CWDS—5,000-15,000 volts, outdoor wound type with stud primary bushings.


Type CW — 23,000 volts and up, outdoor oil filled.


Type BK1-2-3—5,000-15,000 volts, indoor bar type.

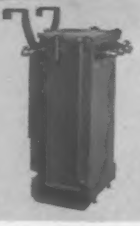

Type MK1—5,000 volts, indoor wound type.

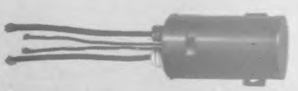

Type K3D—15,000 volts, indoor wound type with double secondary winding for metering and relaying.

POTENTIAL TRANSFORMERS
FOR ACCURATE METERING


Type PD—Up to 13,800 volts, indoor dry type.


Type PW—Up to 13,800 volts, outdoor, oil filled.


Type PCW Metering Outfit — Combined current and potential transformers, up to 69,000 volts, outdoor, oil filled.


Type PWD—Up to 6,900 volts, outdoor, compound filled.

YES, whatever type of transformer you need . . . from high voltage accuracy to low-cost tripping . . . there's one in the complete line of Allis-Chalmers Instrument and Metering Transformers that fills the bill . . . and does it at lower all-around cost! Here's why . . .

Allis-Chalmers Instrument Transformers are liberally designed . . . with extra insulation and added active material — increased protection for your equipment. They meet the highest A. S. A. classification for accuracy . . . and each unit checked against Bureau of Standards calibrated equipment.

What's more, tanks are spra-bonderized . . . finished with a triple-coat automobile finish. If oil or Chlorextol-liquid-filled, they're tested under pressure to prevent leakage. And the extra-heavy bushings reduce corona and radio interference to a new low.

Check the transformers shown at left. They're part of the complete line of Allis-Chalmers Instrument Transformers. And, if you need more information, call the district office near you. Or write direct to Allis-Chalmers, Milwaukee.

A-1367

NEWS ON INSTRUMENT TRANSFORMERS!

No additional wall insulator . . . no organic insulation between primary and ground! These are money-saving features of the new Allis-Chalmers "BKA" through type Current Transformers.

The reason: A continuous, solid porcelain insulating tube extends through the transformer. And its metallized interior . . . with pigtail connection to bus . . . prevents corona and radio interference. Continuous ribbon-wound core forces all flux to flow with the grain of the steel. You get improved accuracy over a wide range of burdens.


Type BKA Current Transformer—5,000-15,000 Volts, Indoor Through Type.

ALLIS-CHALMERS INSTRUMENT TRANSFORMERS

A COMPLETE LINE OF CURRENT AND POTENTIAL TRANSFORMERS FOR EVERY SERVICE

ALLIS-CHALMERS

ELECTRICAL REVIEW

CONTENTS

Motors for the Bridge of Ships 5
E. G. MENARD

How Andrew Hallidie Flattened San Francisco's Hills . . 10
A. R. TOFTE

Step by Step 12
F. W. BUSH

What's the Answer? 17

Showers and Cooler 20
C. W. FRANKLIN

The Gas Turbine, Part II 27
DR. J. T. RETTALIATA

New Equipment 34

★

Vol. VI . . . . No. 4

December, 1941

Allis-Chalmers
Electrical Review

Issued quarterly. Subscription rates: U. S., Mexico and Canada, $2.00 per year; other countries, $3.00. Address Allis-Chalmers Electrical Review, Milwaukee, Wisconsin.

Printed in U. S. A.

MOTORS FOR THE BRIDGE OF SHIPS

To aid the peoples resisting aggression, America's "bridge of ships" spans the oceans of the world. Performing many essential functions under difficult conditions on the modern cargo vessel, destroyer or battleship, marine motors maintain a reputation for reliability.

E. G. Menard

ELECTRICAL DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

● The modern cargo vessel, destroyer, or battleship is more completely electrified than most modern homes. From the electrical range in the cook's galley to the main propulsion motors, electrical energy is utilized to the fullest for its clean, quiet, and dependable year 'round service.

In the present stage of development of electric and mechanical drives, it is necessary that certain considerations be understood before the application can be recommended. The final choice of a ship's propulsion results from carefully weighing all of the factors relative to the specific operation and duty of a ship. There is no one type of drive that can be said to be the best for all applications. In some cases a straight mechanical drive is unexcelled, in others the straight electrical is best, and often a successful combination of the two is achieved.

The electrical drive, for example, when compared with direct or geared mechanical drive, adds considerably to the weight of the boat and has a loss which may run between six and ten percent of the prime mover capacity. On the other hand, the electric drive gives the utmost in flexibility in maneuvering, and in the case of the d-c drive the full capacity of the prime mover may be utilized over a wide range of propeller speeds. As a compromise, composite mechanical and d-c drives are being developed which are an improvement in the values of weight, space, cost, and efficiency limitations of a full electric drive.

Marine type motors, whether for propulsion or auxiliary service, are a relatively new adaptation of the old familiar direct current motors, squirrel cage induction motors, wound rotor induction motors, and, occasionally, the synchronous motor.

AT LEFT: Driving pumps below deck are four 10 hp squirrel cage motors. In the foreground two 1160 rpm machines are coupled to main engine oil pumps; in the background two 1750 rpm units, to coolant pumps.

Propulsion equipment

The main propulsion equipment may be divided into four groups, only two of which are electric drives:

1. Single or multiple geared diesel drive consists of one or more diesel engines connected to the shaft through reduction gears.

2. Single or multiple geared diesel-electric drive consists of a diesel-driven generating plant electrically connected to the propulsion motors.

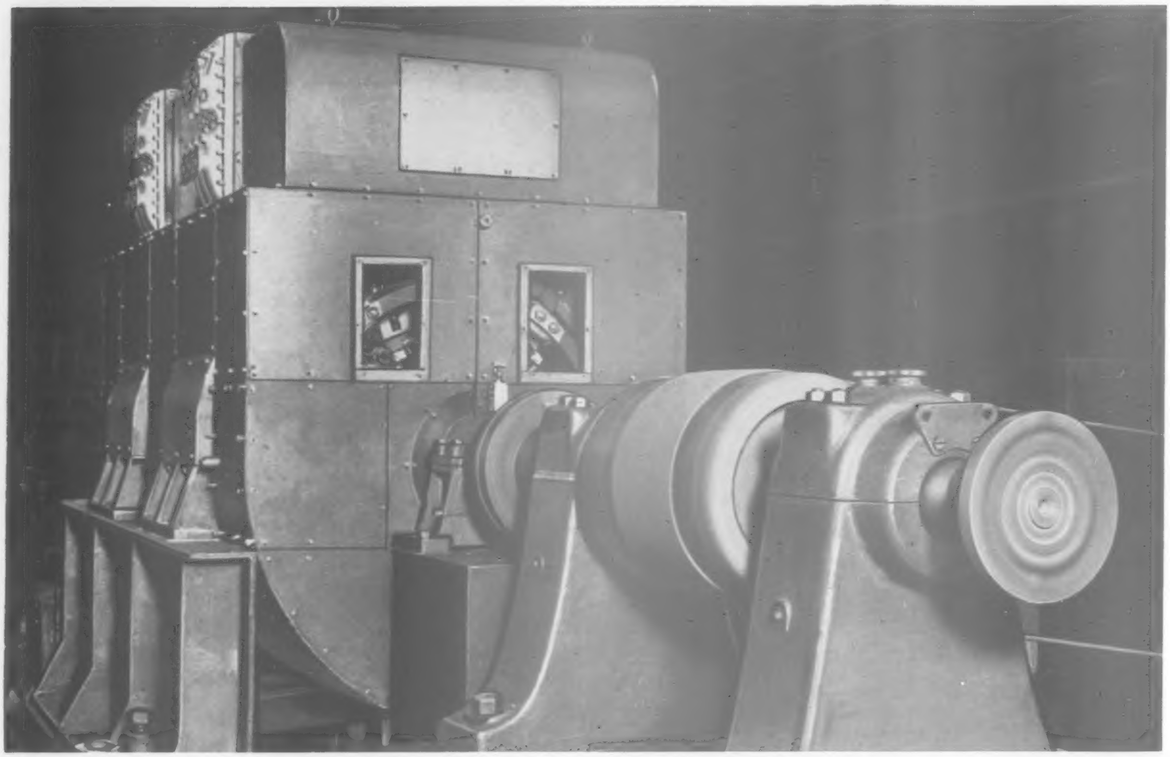
3. Turbine-electric drive consists of a turbine-driven generating plant electrically connected to the propulsion motors.

4. Geared turbine drive consists of a turbine delivering power to the propulsion shaft through a reduction gear.

On the following page is shown a 2880 hp, double armature, direct current, light weight, marine type, main propulsion motor. The ventilating air stream forms a closed circuit. Uniquely designed air vanes in the end covers deflect the hot air from the two commutators over the heat exchangers built into the top of the machine.

Motor applications to shipboard auxiliaries

While the characteristics of the various available types of motors and the means of speed control are well known, the following brief summary indicates the availability of different motor types and speed controls for shipboard use.



A high horsepower-weight ratio is important in marine propulsion drives. Note the compactness of this 2880 hp, double-armature d-c motor.

Shunt wound motors or compensated shunt wound motors are perhaps the most common and are widely used for many applications. The shunt motor embodies excellent torque characteristics and practically constant speed over the entire load range. It is a relatively simple matter to control the speed by field control, armature control, or a combination of both. Speed control by the armature resistance method gives poor motor efficiency and regulation at reduced speeds, but for a given current the motor torque remains the same.

Series wound motors are capable of exerting large starting torque, the maximum being obtained at low speeds. With constant terminal voltage, speed varies almost inversely as the square of the torque. For a given load, lower speeds are obtained by reducing the voltage across the armature, higher speeds by shunting part of the current from the series winding.

Compound wound motors are a compromise between the series motor and the shunt motor. By this means desired speed regulation is obtained simply by changing the degree of compounding. Speed adjustments are made by the same methods as those employed for shunt motors.

Squirrel cage induction motors are essentially constant speed motors and, because of their relatively high starting current, are not so adaptable to frequent starting and stopping. High resistance rotors are used if greater starting torque is desired, but high slip and low efficiency are the result. A tapped stator or a two-winding stator provides two or more constant speeds. The ruggedness and simplicity of squirrel cage motors justify their increasing use for constant and adjustable speed service.

Types of d-c control

In every marine installation emphasis is placed on the control of the equipment involved. This does not necessarily mean the starting and stopping of the unit, but rather the control of that unit while it is operating. To this end the direct current motor lends itself most readily and most efficiently as the means of powering the vessel and its auxiliaries. Each of the following methods of speed control for d-c motors is peculiarly adapted for a particular application and is used as required.

Armature control
- (a) By resistance
- (b) By variable voltage

Field control

Armature plus field control

Armature resistance control is accomplished by changing the value of an external resistance placed in series with the motor armature. Speed can be made to vary from the basic speed at full terminal voltage and full field to any lower value since the speed of a d-c motor is directly proportional to the applied armature voltage. The most serious objection to armature resistance control is that the efficiency decreases more than directly with the reduction in speed since considerable power is lost in the form of heat in the armature resistor.

Variable voltage control is much the same as armature resistance control except in the way in which the applied voltage is varied. The generator field is varied to obtain the desired terminal voltage on the motor. The disadvantage of this system is the requirement that all the motors energized by the same generator must vary simultaneously.

Field control is accomplished by placing a variable resistance in series with the shunt field circuit. A decrease in field current causes a decrease in the counter emf developed by the motor, allowing more armature current to flow. The machine increases in speed until equilibrium is re-established. The efficiency losses by field control are slight, and field control is therefore more desirable than armature control when speeds above base speed are desired.

The combination of armature and shunt field control is frequently employed when the total speed range is outside the limit of either one or the other of these methods alone.

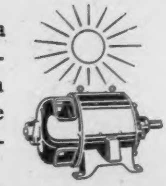
Classification by type

Because of the nature of their work and the many places on shipboard where they carry out their strenuous assignments, marine motors are designed to operate under all possible types of operating conditions. The degree of exposure of a motor to salt air, splashing, or complete submersion determines the extent of the cover protection.

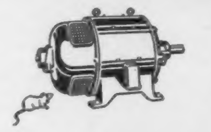
Driving motors of the auxiliary equipment may be classified as below deck and above deck. Below deck motors are usually drip-proof or splash-proof, whereas above deck motors are almost entirely limited to waterproof construction.

With reference to these enclosing covers the following types of motors are considered as standard for shipboard use:

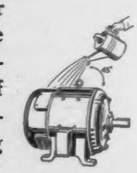
- Open
- Semi-enclosed
- Drip-proof
- Splash-proof
- Totally-enclosed
- Waterproof
- Submersible
- Explosion-proof



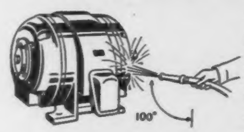
Open motors. An open motor is a motor without any restriction to ventilation other than that imposed by a good mechanical construction. There is no protection from falling or splashing liquids or particles.



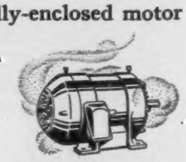
Semi-enclosed motors. A semi-enclosed motor is one protected with wire screen, expanded metal or perforated covers over the ventilating openings in the frame. The openings in the protective covers shall not exceed ½ sq in. in area and shall be of such a shape as not to permit the passage of a rod larger than ½ in. diam. If the distances of the live parts from the protective covers is 4 in. or more, the openings may be ¾ sq in. in area. These covers make a motor vermin-proof.



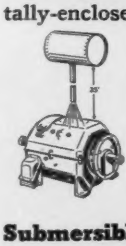
Drip-proof motors. A drip-proof motor is constructed to exclude falling moisture or dirt from any direction up to 15 degrees from the vertical. A drip-proof motor generally has screens or perforated covers on the lower ventilating openings affording vermin protection.



Splash-proof motors. A splash-proof motor has its ventilating openings so constructed that drops of liquid or solid particles falling on, or coming toward it, in a straight line at any angle not greater than 100 degrees from the vertical, cannot enter the motor. The construction includes protection from liquids striking and running along the surface within the above limits.



Totally-enclosed motors. A totally-enclosed motor is constructed to prevent the circulation of outside air through its interior. The motor is not necessarily completely air tight and is not water tight.

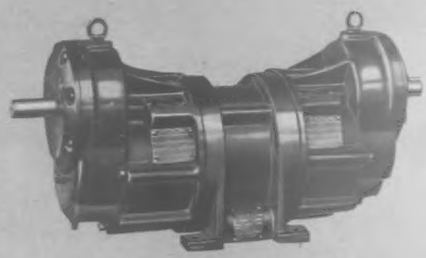


Waterproof motors. A waterproof motor is a totally-enclosed motor so sealed by precision machined joints and gaskets that a stream of water (not less than 1 in. diam), at a distance of 10 ft and with a 35 ft head, can be played upon the machine for a period of five minutes without leakage or wetting of the interior.

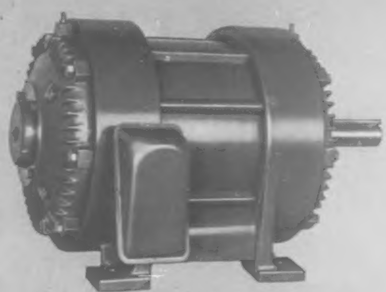
Submersible motors. A submersible motor is one so constructed that it will operate successfully com-

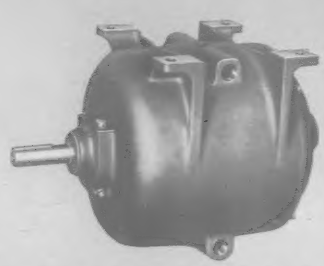

Drip-proof Motor for Ceiling Mounting


Drip-proof Motor Close-coupled to Pump

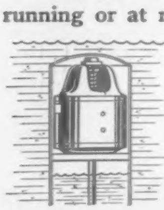

Splash-proof Gearmotor Design


Vertical Drip-proof Motor


Totally-enclosed, Fan-cooled Motor

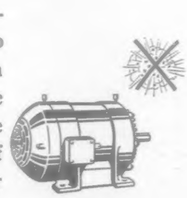

Totally-enclosed, Water-cooled design

pletely submerged in water under specified conditions of pressure and time. A typical test of submersibility is the placing of the motor in water under a pressure of 10 lb per sq in. for one hour while the motor is running or at rest without leakage into the interior.



A specialized branch of the submersible application is the diving bell protected open motor. A vertical motor with mountings and extended shaft is enclosed in a bell or dome, designed to retain sufficient air for cooling and to keep the water under a predetermined head from touching the motor. Such installations are usually best suited for intermittent duty since it is difficult to cool the motor in such a confined space.

Explosion-proof motors. An explosion-proof motor is one designed to withstand an explosion of a given quantity of gas or dust within the motor housing, or to prevent the ignition of a specified quantity of gas or dust surrounding the motor by internal sparking or explosions.



Duty classification

In addition to the factors influencing the housing design, the rating of marine motors is affected by the service intended. Marine service calls for the accurate appraisal of the duty cycle of the various installations. A motor rated for continuous duty where a short-time rating would be sufficient will mean an over-powered unit, the extravagant use of floor space, and low efficiency. Under-rating an application results in overheating the motor and frequent repairs.

The duty cycle to a great extent governs amount of enclosure that can be successfully used without going to a larger frame to provide additional heat dissipating area. It is not uncommon for a continuous duty, totally-enclosed, waterproof motor to require a frame three or four sizes larger than the equivalent-rated open motor. Intermittent duty for the same installation may require a frame but one or two sizes larger.

Duty classifications for motors have become standardized and apply not only to motors for marine service but to all types of motors. Following are the duty classifications for various types of motors:

Continuous duty is a service requirement demanding constant full load for an indefinite period.

Short-time duty is a service requirement demanding constant rated load for a specified period.

Intermittent duty is a service requirement demanding specified alternate periods of load and rest.

Periodic duty is a service requirement demanding alternate periods of load, no load, and/or rest. The load conditions are defined and recurrent.

Varying duty is a service requirement demanding wide variations in periods of load, no load, and/or rest. The motor to meet this duty classification is designed to operate at one-fourth rated load until the temperature is stabilized, followed by full load for a predetermined period without overheating.

Corrosion protection

The vital parts of marine type motors are protected in some fashion from the corrosive action of moist air, frequent splashings, and the high ambient temperatures (assumed to be 50 C and often higher). The materials selected for insulation are those having the lowest relative water absorption or those having dielectric properties least affected by water absorption. Insulating materials are selected to retain their original toughness and resistance to shock and vibration after long periods of subjection to heat and moist salt air. To meet such "tropical service conditions" insulation is given extra dips of special varnishes and subsequent bakings. Glass insulation has proven to be very satisfactory for marine service, but it is not universally accepted unless used in conjunction with a mica cell against the slot metal.

All bright parts are given several coats of varnish, resistant to salt air, or are manufactured from corrosion-resisting materials. Bolts, studs, nuts, pins, screws, terminals, springs, brush rigging, etc. are made of brass, bronze, phosphor bronze, or aluminum alloys. Parts that cannot be made of corrosion-resistant materials are galvanized, sherardized, or are cadmium-, phosphate-, zinc-, chromium-, or copper-plated. Cadmium plating is not being used as much as formerly, for it tends to decompose and lose its protective qualities in a confined space with certain kinds of varnishes.

Motors for marine auxiliaries

Winches are driven by totally-enclosed waterproof motors provided with double shaft extensions for the pinions and brake. Series or compound windings are used to obtain the necessary high torque at slow speeds. Intermittent or ½-hour rated, they are not as massive as continuous duty waterproof motors. The maximum permissible speed for winch service is 600 rpm, and slower speeds are obtained by armature control.

The capstan or working capstan having a vertical barrel is used for positioning the vessel during docking. A totally-enclosed waterproof horizontal motor may be used when the installation is above deck, driving the barrel through spur gears. Below deck installations are not infrequent, the barrel being then mounted on a long shaft projecting through the deck and driven by a drip-proof motor. A constant speed uni-directional motor, shunt or slightly compound wound, or a squirrel cage motor is suitable since the various speeds are obtained by rope pressure upon the barrel.

Windlass motors

The windlass may be either an above or a below deck installation and, as such, requires waterproof or drip-proof protection. A compound wound direct current motor is more suitable than a series motor for this type of drive although squirrel cage multi-speed induction motors drive many windlasses. These motors will not run away during windlass lowering and afford a good opportunity for dynamic braking.

The subject of ship control circuits is too complex to be included within the limits of this discussion. It is sufficient, for the present, to state that great progress is being made in this direction.

HOW ANDREW HALLIDIE FLATTENED SAN FRANCISCO'S HILLS

Carriages have given way to streamlined automobiles, and the telegraph has displaced the pony express. But the "seven and seventy" hills of San Francisco . . . birthplace of the cable car . . . are still criss-crossed with these symbols of another day.

A. R. Tofte

ADVERTISING DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

● Long tendrils of fog crept in from the bay, covering the lowlands at the base of the hill with drab shadows. Although the day promised to be hot and sultry, the group of men on top of the San Francisco hill felt the chill of the early hour. One man, however, was obviously excited and warm.

"But, Mr. Hallidie," someone said to him, "if the brakes don't hold, the car will go right on into the bay. We'll all drown."

"No one need go who is afraid," Hallidie replied. Then he looked at the crowd of men around him.

It was the first day of August, 1873, and Andrew Hallidie knew it was the most important day of his life. Somehow in the next few minutes he had to prove to these men that there was nothing to be afraid of, that the cable street car he had invented could go down the Clay Street hill without danger. He motioned for the gripman to take his place at the controls. Most of the men in the crowd fearfully got into the car.

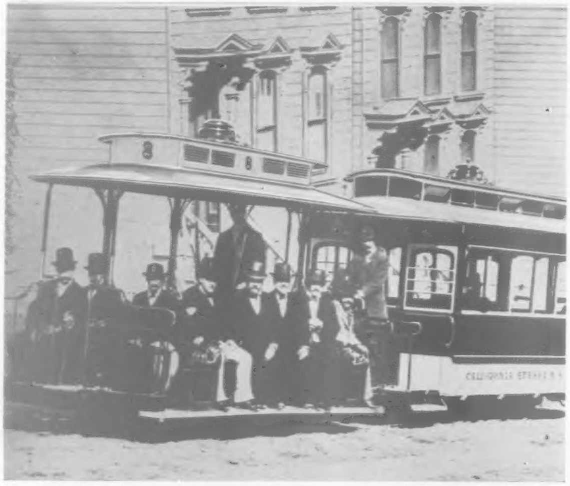
But the car did not start at once. The workman at the controls was looking at the steep hill in front of him and at the fog-covered bay below. The man's face was pale. Hallidie tapped him on the shoulder.

"Not worried, are you?"

"I'm afraid I am, Mr. Hallidie," he confessed. "I'm sorry, but I haven't the nerve."

Hallidie hesitated only a moment. His whole career was at stake. Without a word, he motioned the man away from the controls, took them over himself.

He lowered the grip. It caught the underground cable, and the car jerked into motion. Down the hill it went, coming to a stop at the bottom, safe and completely under control. Hallidie turned to his passengers.



Built in 1878, this California Street cable car was the "last word" in street railway transportation. Cars of this type were abandoned in 1889.

"Now we'll take the car back up," he said triumphantly.

Thus was the world's first street cable car tried for the first time. Only about a dozen blocks long, the original Clay Street line was pioneer to a network of cable lines all over San Francisco. The idea spread quickly, for cable cars offered many advantages over horse-drawn cars. Chicago installed a cable car system in 1883. About the same time, the Brooklyn Bridge Railway was formed as a cable car system and carried an average of 35,000 people in the single evening rush hour. Cable car systems were built in New York, Philadelphia, Paris, and scores of other large cities.

But as quickly as they had risen to popularity, they fell out of favor. Electric trolley cars, with greater speed and flexibility, came in, and cable cars soon became as outmoded and obsolete as horse cars.

But not in San Francisco!

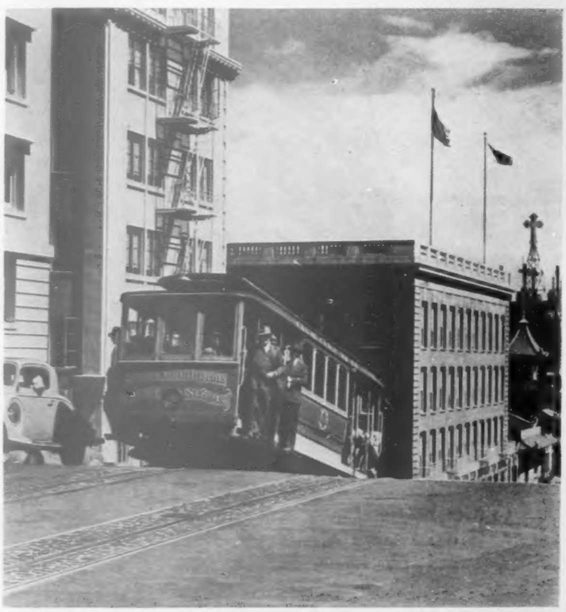
Here trolleys supplanted cable lines on the more level stretches. But, contrasted to Rome with its seven hills, San Francisco with its "seven and seventy hills" obviously needed something more suitable to hill climbing than trolleys.

So the cable car system stayed. Following the success of the Clay Street line in 1873, Governor Leland Stanford built the California Street line to fashionable Nob Hill in 1877. By 1895 there were 17 different street railway systems in San Francisco.

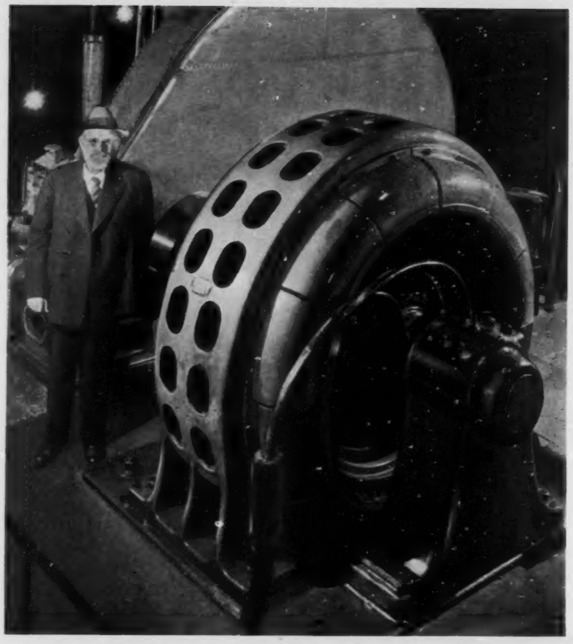
Clumsy, slow, uncomfortable, San Francisco's cable cars, with over 100 miles of track, are still the best means that have been devised for scaling the "seven and seventy" hills.

To the tourist or stranger, riding a cable car is quite an experience. The gripman (operator) skillfully works a lever that controls a grip on the underground cable. Going at a steady 8½ miles-per-hour pace — up grades as steep as 21 percent, down hill, and around corners — the gripman clangs his overhead gong incessantly in warning for everybody to get out of his way. This is no idle threat, for to stop the car he must work a cumbersome lever that releases the cable, and then he must apply the brakes. In emergencies the conductor also gets busy and applies brakes on the rear end.

The California Street line is typical of San Francisco's cable lines. Originally it ran on California



The rider on a San Francisco cable car learns to balance himself on sudden grades or when it swings around corners at the same speed it has on straightaways; for cable cars have only one speed — 8½ miles per hour.



Two 300 hp synchronous motors keep 11 miles of underground cable in steady motion 20 hours a day to operate the California Street cable car system. These motors have been in operation 26 years without a shutdown. Shown here with one of the motors is 86-year-old James W. Harris, who recently retired as president of the company after 62 years of service.

street from Kearney to Fillmore streets, and was powered by a steam engine located in a power station at California and Larkin streets. When the Hyde and Jones Street system was added in 1891, the main station was moved to the present location at California and Hyde streets.

About 34 cars are operated, each car seating 35 people, although during rush hours upwards of 100 passengers try to climb in at a time. Approximately 60,000 feet of continuous cable are used and must be replaced about every five months. The cable operates at a steady speed of 8½ miles per hour from 5:45 a. m. until one o'clock the next morning.

The plant was destroyed in the fire and earthquake of 1906, and many changes in equipment were made in the ensuing reconstruction. Early in 1915, two new 300-horsepower synchronous motors were installed to drive the 60,000 feet of cable. These motors, one of which is shown in the accompanying photograph, are still in service.

So — when you go to San Francisco — don't fail to take a ride on a cable car. It's part of the unique and glamorous atmosphere of this interesting city.

Oldtimers will even tell you that, since the cars swing you around a lot, you should be sure to pick the right kind of neighbors, for you never can tell when you come out of a turn if you'll have a pretty girl or a coal heaver on your lap.

STEP BY STEP

Operating under a wide variety of applications and conditions for nearly a decade 5/8% step type feeder voltage regulators in practice confirm their anticipated theoretical advantages.

F. W. Bush, **Assistant-to-Manager**

ELECTRICAL DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

● When the 5/8% step regulator was first introduced nearly a decade ago, considerable interest was aroused as to its ability to stand up in service and give as good regulation as the regulators then available for regulating the voltage on distribution feeders. The step regulator, using transformer construction, introduced several innovations, such as higher impulse strength, lower exciting current, lower losses, elimination of twisting leads, avoidance of motor brakes, etc.; but it was feared by some operators that the tap changing mechanism might require undue maintenance because of contact wear or mechanical difficulties. It was also anticipated that the voltage regulation produced in steps would not be satisfactory for urban feeder service.

These were natural anticipations; for, previous to the introduction of the modern step regulator, tap changing equipment with only coarse steps of 2½% or 1¼% had been built, and the mechanisms had required frequent contact replacement. The use of time delay in the control circuit was also a matter of controversy. In view of the wide acceptance of the step regulator today, it may be of interest to review some of the early fears in the light of nearly a decade of operating experience.

Size of step

It had been universally recognized that the smaller the voltage step the better the regulation, but it was suggested that the 5/8% step might be too small and would cause the tap changer to operate too frequently, thereby causing excessive wear on the contacts. Therefore, early step regulators were arranged to provide steps of 2½%, 1¼%, and 5/8%. The 2½% step regulator was short-lived, since this size step was too coarse for the close regulation demanded by most users of electric power. Subsequent installations were then limited to the 5/8% step type and the 1¼% step type; and, after a few years of actual service experience, the 5/8% step type was adopted as standard for station type regulators. The reason for the swing toward 5/8% steps was twofold — better regulation and fewer instead of more tap changes. That better regulation would be obtained with 5/8% steps was self-evident, but the fact that fewer tap changes would result was a little more difficult to visualize.

Figure 1 illustrates the operation of the 5/8% and 1¼% step regulators on a typical fluctuating feeder. "A" indicates a typical voltage fluctuation on the source side of the regulator, and "B" shows the regulated voltage when 5/8% half-cycling steps are used. "C" shows the regulated voltage when 1¼% full-cycling steps are used. In both charts "B" and "C" it is assumed that the voltage control relay is set to maintain a voltage band of plus and minus 1%. It will be noted that it requires two 5/8% half-cycling steps to maintain voltage on the 5/8% step regulator, but in the case of the 1¼% full-cycling machine nine full cycle steps are required. Since each 1¼% full cycle step is in reality two 5/8% half-cycling steps, the actual number of switch operations in the latter case is eighteen, while in the former it is only two. These charts clearly illustrate one of the reasons why modern station type step regulators are now provided with 5/8% half-cycling steps.

Close regulation

In addition to causing fewer operations, the 5/8% half-cycling step regulator has provided, in actual service, voltage regulation as close or closer than that provided by any other type of regulator. Service experience was necessary to prove this point definitely, for it was difficult to understand how a regulator which moved in steps could regulate as well or better than the theoretically stepless induction regulator.

It must be remembered, however, that there are inherent limitations in the setting of the automatic control devices of the induction regulator. These are due to the adjustments of the contact-making voltmeter with its associated compounding coils and the drift, caused by imperfect braking, which usually make the induction regulator operate in approximately 1% steps rather than the 5/8% steps obtained with the step regulator. The theoretically stepless operation of the induction type of regulator is therefore not borne out in practice.

Integrating time delay

Another factor contributing to closer regulation has been the use of integrating time delay in the control circuit of step regulators. While time delay was formerly considered a necessary evil, to be avoided if at all possible, years of operating experience have shown that better regulation can be obtained on most feeders by the use of time delay, provided that it is of the "integrating" variety. By "integrating" time delay is meant one which will algebraically add the voltage fluctuations in such a way as to maintain always the best average voltage.

This is accomplished by means of a time delay contactor so designed that the return speed is approximately equal to the forward running speed. By this means the contactor integrates or algebraically adds the voltage fluctuations. If, on rapidly varying voltages, the voltage is either high or low for a longer period of time than it is correct, the contactor will allow the regulator to operate and correct it. This control results in the correct average voltage being maintained at all times — even on widely fluctuating feeder voltages.

If no time delay is used on a feeder that is subject to wide fluctuations, it has been found that the contacts of the contact-making voltmeter must be set farther apart to prevent the regulator from overshooting. This practice, of course, results in coarser regulation. Since no feeder regulator can respond instantly to a change in voltage, it is impossible to correct short fluctuations before they are apparent to the consumer. Consequently, it has been found that a fast operating regulator will cause over-shooting and make the fluctuations more apparent by doubling their number; that is, a fast operating regulator will correct a voltage dip as soon as it occurs, but it must again correct it when the voltage recovers. Thus, there are four distinct voltage changes — the dip, the correction, the recovery, the recorrection — instead of only the two — the dip and the recovery — which result when integrating time delay is employed.

In addition to providing better regulation, integrating time delay reduces the number of tap changes made by the tap changing mechanism. The most desirable setting of the time delay contactor, of course, varies with different installations, but in general it has been found that settings as high as 60 seconds may be used on most feeders with no sacrifice in close regulation. Fig. 2 illustrates the relation between the time delay setting and the tap changer operations obtained on two typical feeders.

The voltage charts shown in Fig. 3 illustrate the difference in voltage regulation obtained on another feeder with the integrating time delay contactor set at various amounts of time delay. It will be noted that in this particular case the chart obtained by using the 30-second setting (No. 4) was somewhat better than the others, and therefore a time delay setting of 30 seconds was selected for this particular regulator. It is particularly interesting to note, however, that the 15-second chart (No. 3) shows poorer regulation than the 30-second chart (No. 4).

Since most feeders have slightly different characteristics, many operators try a number of time delay settings before selecting the one best suited for the particular application. The majority of installations, however, find that settings between 30 and 60 seconds give excellent results.

Contact life

The fear of frequent contact replacement was probably the greatest obstacle which the step regulator had to overcome before it gained the wide acceptance that it enjoys today. Early factory tests had indicated

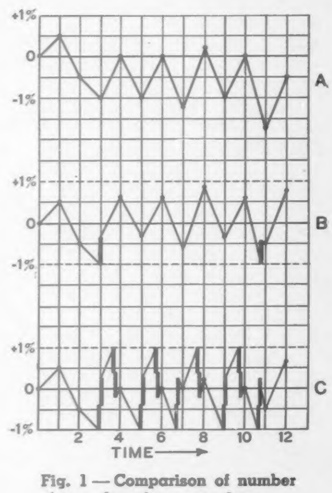


Fig. 1 — Comparison of number of tap changing operations.

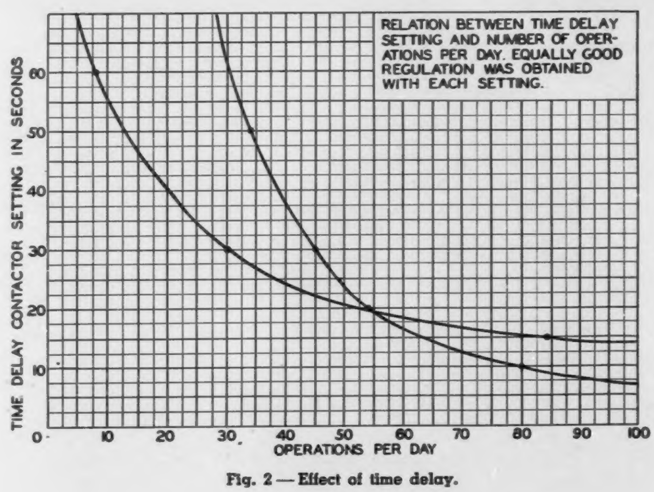


Fig. 2 — Effect of time delay.

that properly designed tap changing mechanisms could be expected to last as long as the transformer parts without contact replacements being necessary, but this performance was so radically different from previous service experience on former circuit breaking equipment that it was not until several years ago that these early factory tests were definitely verified by actual service experience.

Now, with one make of step regulator having a record of nearly a decade of field experience with never a contact replacement due to deterioration in normal service, it is generally conceded that the contacts of a properly designed tap changing mechanism should last as long as the rest of the regulator or the transformer parts.

This long contact life can be attributed to the careful consideration given to each of four fundamental factors investigated in the early factory tests — kva to be interrupted, speed of the contact separation, size of the contact structure, and composition of the contact material.

Kva to be interrupted. It is evident that the smaller the kva to be interrupted the longer the contact life; and, since this kva is directly proportional to the voltage between taps, it is important that small steps be used. For this reason, as well as others previously mentioned, ⅝% steps were selected.

Speed of contact separation. It has long been known that the faster the contacts are separated the

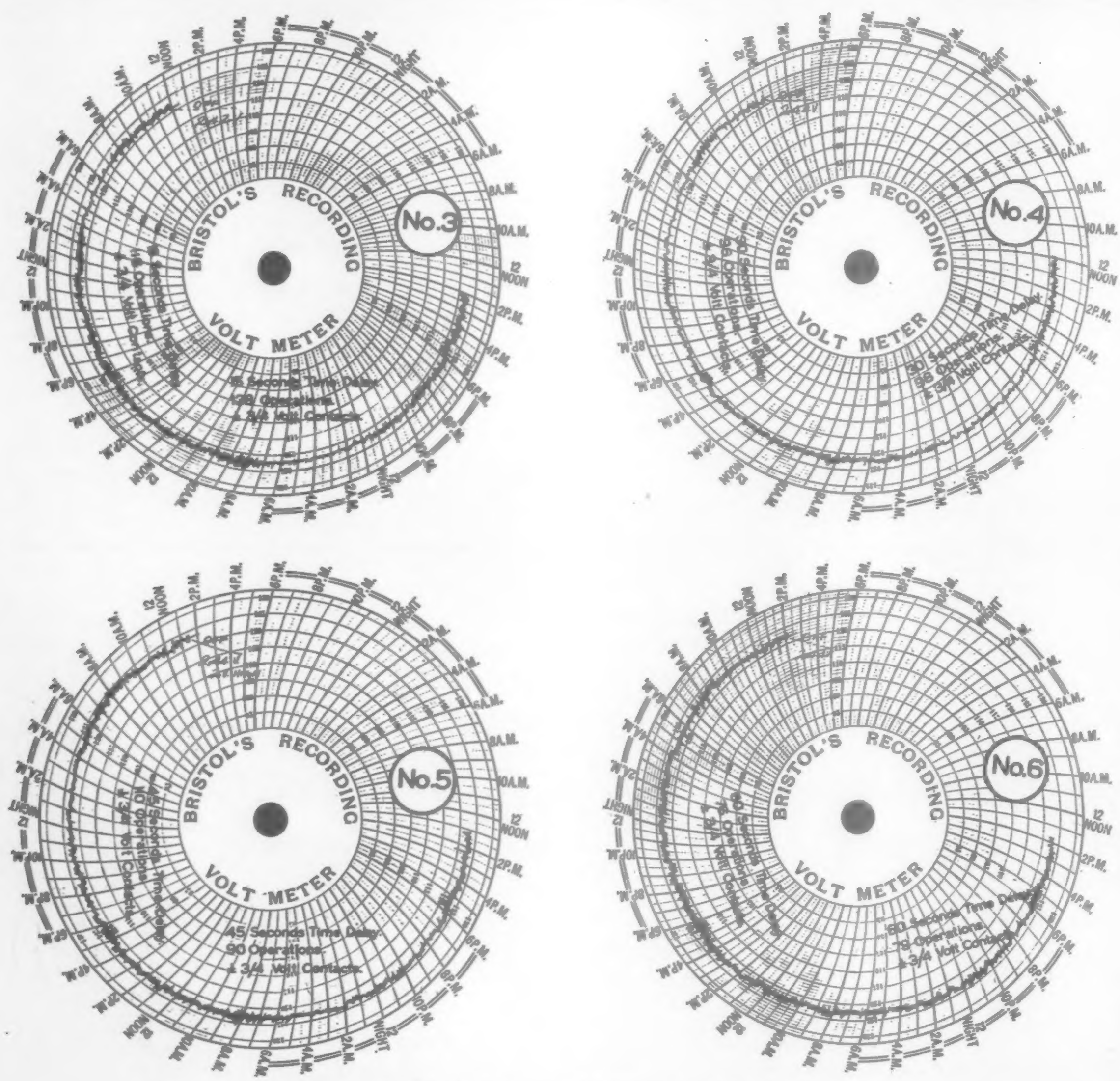


Fig. 3 — Voltage charts show value of correct time delay setting.

longer the contact life. This fundamental law has been recognized in the design of all circuit interrupting apparatus, from the small snap switch which handles a few volt-amperes to the large oil circuit breaker handling millions of kva. Early tests on tap changing contacts again confirmed this law, and therefore a balanced spring-operated quick-break mechanism was adopted to move the contacts from one position to the next in about two cycles.

Size of contact structure. Other things remaining equal, early tests indicated that the larger the contacts the longer their life. This, of course, is due to the increased thermal capacity of the larger contacts; and for this reason extra large contacts were selected for the original ⅝% step type regulator.

Composition of contact material. The problem of selecting the proper contact material, although no more important than the other factors, was considerably more difficult because of the almost unlimited number of materials available. After scores of different materials had been tested, two were selected as being outstanding. One of these was a copper alloy, while the other was one of the numerous grades of Elkonite.

Because of its availability and low cost, hard-drawn copper was naturally one of the first materials tested; but it was found to be wholly unsuited for this service on account of its limited life. Fig. 4 shows the results of a test made on a copper contact compared with an Elkonite contact which had the same duty. Fig. 5 shows the appearance of a pair of Elkonite contacts after the equivalent of 2,000,000 tap changes on a ⅝% step regulator of average size. Since years of service experience have shown that most regulators average about 10,000 to 40,000 tap changes per year, it seems safe to predict that contacts designed along the lines described should never need replacement.

Oil maintenance

It was only natural to assume that the arcing of the tap changer contacts would cause the tap changer oil to deteriorate faster than the transformer oil, but tests made during several years on regulators in actual service fail to uphold this assumption. In fact, the field tests indicate that there is no appreciable difference in the rate of deterioration between the oils in the two compartments. The tabulation below shows the results of tests made on a number of different regulators after approximatey three years of service.

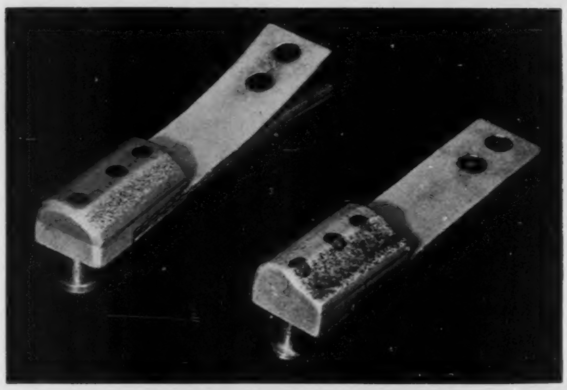


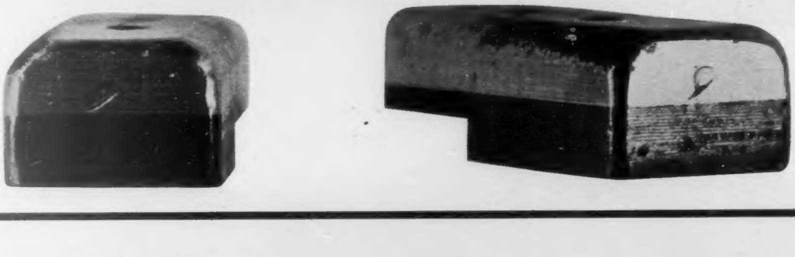
Fig. 4 — Elkonite (left) and copper contacts.

Test No.	Mechanism Compartment Dielectric Test, Kv	Transformer Compartment Dielectric Test, Kv	Operations
1	22	18	34,195
2	18	21	36,412
3	20	20	42,262
4	20	20	36,838
5	22	28	59,189
6	28	30	124,847
7	29	28	79,324
8	25	16	35,596
9	23	15	52,300
10	19	25	36,701
11	22	17	38,806

From the above tests it will be noted that in five of the regulators the tap changing mechanism oil tested better than the transformer oil; while in four others the opposite was true, and in the two remaining units both oils tested the same. Tests for acidity likewise show that there is no appreciable difference between the two oils. The reasons for these unpredicted results are probably the same as those which produce long contact life — minimum arcing because of large contacts of non-arcing metals operating over small steps at high speed.

In view of the service experience with step regulator oil, most operators are now maintaining it on the same basis as any other oil-filled apparatus in similar service.

Fig. 5 — Elkonite contacts after the equivalent of 2,000,000 tap changing operations.



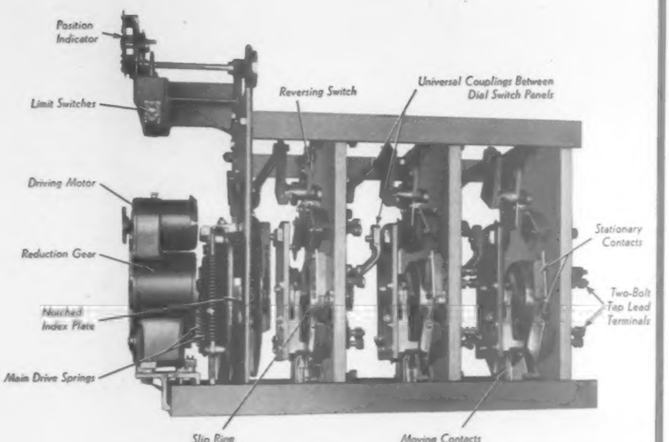


Fig. 6 — Typical three-phase operating mechanism of ⅝% step type feeder voltage regulator.

Fig. 7 — Unit-built regulator control panel of latest design.

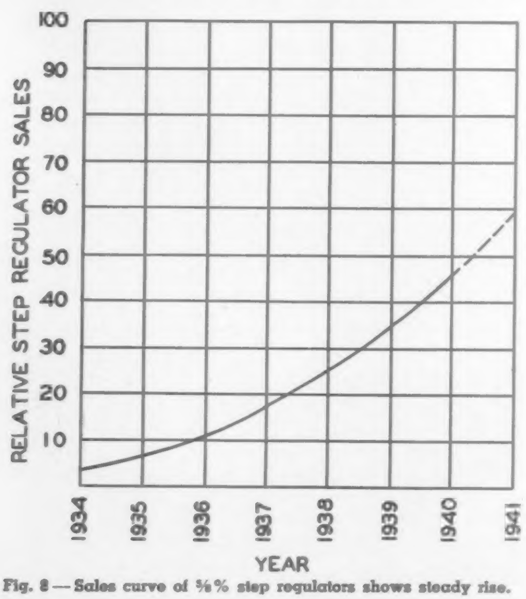


Fig. 8 — Sales curve of ⅝% step regulators shows steady rise.

Mechanism life

As previously mentioned, one of the important factors in obtaining long contact life is the speed of contact separation. This naturally requires mechanical construction capable of operating at very high speed. This fact alone led some to believe that the tap changing mechanism of the step regulator would require undue maintenance because of mechanical wear. Although early factory endurance tests had shown that mechanisms were capable of running 5,000,000 operations without maintenance, it was not until many years of actual service experience that this fact was firmly established. One of the most important reasons for this long mechanism life can be attributed to the selection of a balanced spring design, in which one operating spring acts as a snubber while the other spring does the driving.

This principle of operation not only gives high contact speed but at the same time prevents shock when the high-speed parts are brought to rest. Long spring life was assured by operating the springs at low stresses and by fitting the ends with special machined plugs instead of the conventional loops. These plugs eliminated the indeterminate end stresses which are always present when loops are used. In addition, the balanced spring principle provided a self-centering action which eliminated the need for a motor brake and its attendant maintenance.

The elimination of the brake also permitted mounting the entire mechanism, including the operating motor, under oil, which further decreased maintenance by eliminating the need for periodic cleaning and lubrication. A typical three-phase mechanism of the type described is shown in Fig. 6.

Because of the excellent operating record established during the years that ⅝% step regulators have been in use, most operators have placed step regulators on a four or five year inspection program. Even on this schedule many operators report that no maintenance is necessary; hence it is believed safe to predict that after a few more years of operating experience, the average inspection program will be on a ten year basis — if not longer.

Automatic control

It was only natural that the automatic control devices furnished with the first step regulators were practically the same as those used previously with induction regulators since the functions of the two machines were identical. The addition of the integrating time delay contactor, however, made a very important difference in that it permits the elimination of holding or compounding coils on the contact-making voltmeter. These holding coils were necessary on the induction regulator to prevent burning of the contact-making voltmeter contacts and also to provide a compounding effect to prevent excessive maintenance from chattering secondary relays and solenoid brakes due to frequent starts and stops. In effect, the holding coils caused the induction regulator to operate in steps of a size that depended upon the holding coil

adjustment, which in turn depended upon the allowable maintenance and wear on the regulator.

These holding coils are not necessary on the control of the step regulator when the integrating time delay contactor is used since this contactor consists of a small induction disc motor, and the contact-making voltmeter merely controls the low-energy operating coil circuit rather than the high-energy field circuit. This important difference in the two control circuits makes possible a contact-making voltmeter with "feather-touch" action that is free to follow each voltage change without the danger of burned contacts or excessive regulator operations. Years of field experience with this type of control indicate little or no maintenance necessary on the contacts of the contact-making voltmeter, while with the older type of control contact dressing was necessary every month or two.

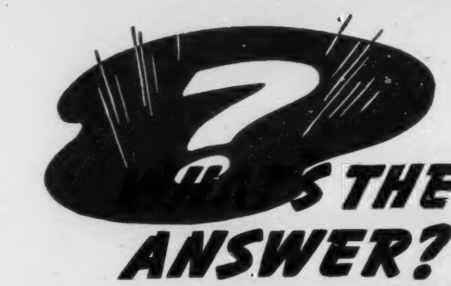
For traditional reasons the early step regulators were provided with automatic control equipment consisting of separate instruments, each housed in a separate case and assembled together on a control panel. This method of construction has since been superseded by the unit-built control panel in which all of the control devices are mounted behind a dead-front panel, as shown in Fig. 7. This type of construction is considered by most operators to be a great improvement over the former construction, since it permits all settings and adjustments to be made by simply turning knobs, and there is no danger of touching live parts. The panel is hinged to permit easy inspection of the various elements.

Economic considerations

Economically as well as mechanically the step type regulator has earned an enviable reputation during the years that it has been commercially available. It has made possible the regulation of the higher voltage feeders, which was heretofore impractical with other regulators. Even small 2400 volt circuits can now be regulated at a cost reduction of 10 to 15 percent in first cost alone.

Additional savings have been made possible in substation construction because of the self-contained features introduced by the step regulator. Insulation levels have been raised so that the regulator no longer requires special consideration in insulation coordination studies. The quiet operation of the step regulator has made it possible to locate outdoor substations even in residential sections, thus saving the cost of expensive sound-proof buildings. The saving in exciting current alone usually amounts to as much as three to five percent of the first cost of the regulator. There is also an appreciable saving in copper loss when the regulator is near the neutral position.

When all of these factors are considered in addition to their excellent operating record, it is not surprising that the use of step regulators has grown by leaps and bounds. Fig. 8 shows the increasing demand for this type of regulator since 1934, and all indications point toward even greater demand in the future.



Question—Why do some direct current generators have three slip rings? —A. E. S.

Answer—Three slip rings are used to bring out leads that are connected 120 electrical degrees apart on the armature winding. This is known as a three-wire generator. A neutral is obtained by connecting three rings to a wye-connected external inductance coil, making it possible to obtain half the rated voltage of the generator.

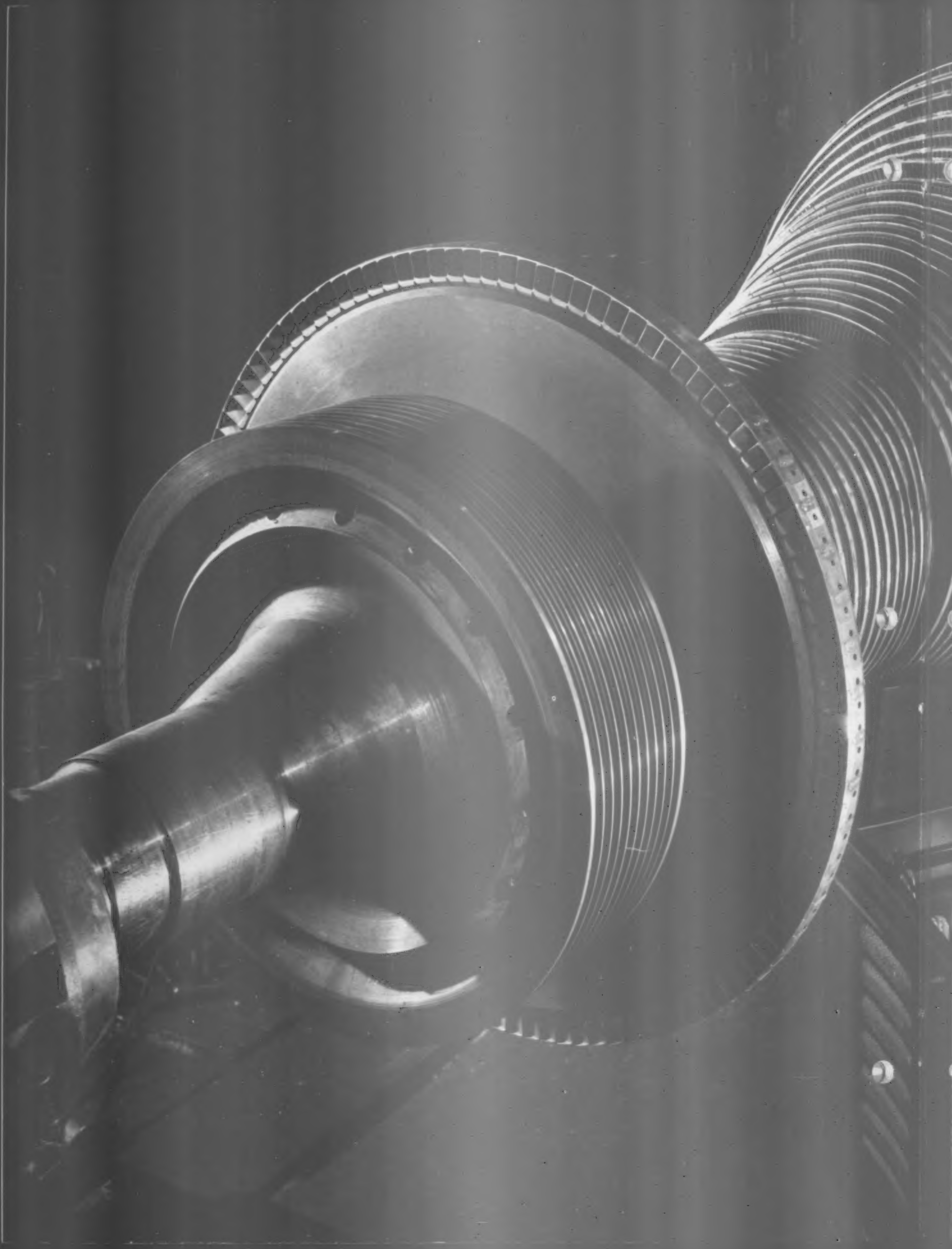
Question—Is automatic control generally applied to phase-shifting under load power transformers? —W. L. P.

Answer—Generally, automatic control is not applied to phase-shifting under load power transformers because a phase-shift secured by a variation in the quadrature voltage, or by a variation in the combination of in-phase and quadrature voltage, may be used to vary a number of line factors each of which is usually controlled independently of the other. For example, the desired amounts of in-phase and reactive kva may vary from one load condition to the next. Under one condition it may be desirable to supply a certain amount of in-phase and reactive kva and compensate for a certain phase displacement, while under the next load condition the desirable values of each factor may be entirely different. Since most automatic control schemes would hold each line factor constant, the usual method of control is by manual adjustment under the supervision of the load dispatcher.

For a reference on the subject, refer to "Accepted Methods of Obtaining Combined Voltage and Phase Angle Control Under Load," December, 1937, Allis-Chalmers ELECTRICAL REVIEW.

"What's the Answer?" is conducted for the benefit of readers of ELECTRICAL REVIEW who have questions on central station, industrial or power plant equipment. Send all questions to the Editors of ELECTRICAL REVIEW.

ON FOLLOWING PAGES: Thin cross-section steam turbine blade shrouding (down to 0.037 in.) can now be arc welded. Here a Weld-O-Tron, which operates on a current of only 5 amps, is used in welding an impulse-reaction spindle.



SHOWERS AND COOLER

Just as summer rains cool the parched earth, water sprays are being utilized to cool transformers hidden in vaults . . . and with the same refreshing results.

C. W. Franklin

CONSOLIDATED EDISON COMPANY OF NEW YORK

● The operation of distribution transformers on a temperature basis, whereby the permissible loading is determined by winding temperature rather than by nameplate current rating, permits a most economical use of transformer capacity. Maximum capacity is obtained if the ambient air temperature around the tank is kept low.

Where a transformer is installed in a compartment, such as an under-sidewalk vault, the rise in vault ambient temperature over the street ambient temperature depends upon the heat losses to be dissipated from the vault and the wall and grating areas available for dissipating these losses. Present-day vaults for standard three-phase network installations are usually small in size, the wall area is limited, and the wall area suitable for dissipating losses may be restricted by other vaults, heated basements, or steam mains adjacent to one or more sides. Restrictions frequently exist on the ventilating grating area. There are instances where a combination of the above conditions so reduces the ability of a vault to dissipate heat that a transformer installed in the vault must be assigned a lower rating than when standard conditions prevail or it will exceed the allowable temperature limits if operated at the standard rating.

This discussion presents data to show the effectiveness of water spray evaporative cooling as an auxiliary means of obtaining maximum rating for a transformer operated in a vault.

Water spray evaporative cooling

Evaporative cooling of air is produced by simply introducing more moisture into the air to increase the humidity and thus lower the dry bulb temperature to, or nearer to, the wet bulb temperature. If the air can be saturated with moisture, the humidity becomes 100 percent, and the dry bulb temperature and wet bulb temperature are equal. When water is finely sprayed as a mist into air of less than 100 percent humidity, some of the moisture will be evaporated, and the dry bulb temperature will be reduced because heat is required to supply the latent heat of evaporation for that portion of the moisture which is evaporated.

The evaporation of a relatively small amount of water requires considerable heat. At ordinary temperatures the dry bulb temperature of a cubic foot of air will be lowered about 8.5 F for every grain of water that can be evaporated into it. On hot summer days when transformer temperatures are of most concern, humidity of the air is usually well below 100 percent so that the air is capable of absorbing considerable moisture.

Water spray evaporative cooling for distribution transformers in vaults consists of introducing a finely divided water spray into a compartment, whereupon the heat required to evaporate a portion of the water is supplied by the transformer tank and vault air. The unevaporated remainder removes an additional amount of heat by direct interchange of heat from the tank wall, and this water drains off into the vault sewer connection. These means of removing heat from the vault are in addition to those involved with natural ventilation; viz., dissipation through the vault walls and the increase of sensible heat content of the air circulated through the vault. Thus a reduction in transformer temperature is effected below that which occurs for the same loading conditions without spray cooling.

Normally, with natural ventilation, the quantity of air which must be circulated through such a transformer vault in order to dissipate heat depends upon the quantity of heat losses to be dissipated and the difference in temperature between the vault air and outdoor air temperatures. The capacity of this circulating air to absorb moisture inside the vault, when water spray is used, depends upon the humidity of the inlet air, the air temperature rise in the vault,

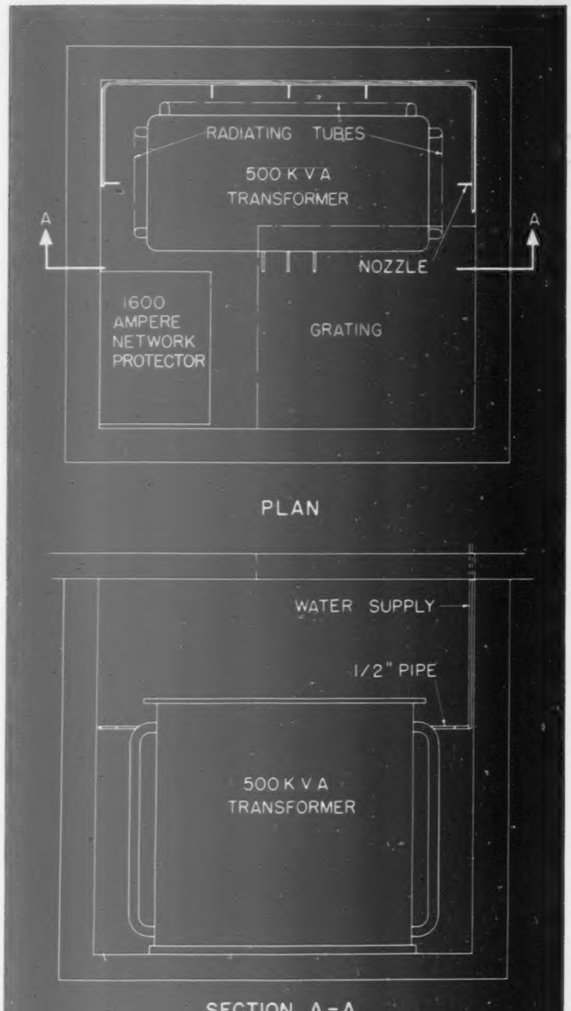


Fig. 1 — Transformer Vault Installation with Provision for Water Spray.

and the quantity of air circulated. Since the air is heated within the vault, its relative humidity is decreased, and its capacity to absorb moisture is increased. However, as moisture is evaporated within the vault, the air temperature rise over outdoor air is lowered with the result that the quantity of air circulated is reduced owing to the reduced "stack" effect.

Cooling effects

While a detailed analysis of the mechanism of heat dissipation which occurs when water spray is used is complex, some material is presented herewith to indicate the cooling effects of evaporating various quantities of moisture and the estimated theoretical maximum amount of water which could be evaporated for stated rates of air transfer and air temperature rise. Fig. 2 shows the relation between kilowatt loss and water evaporation rate, in gallons per hour, required to dissipate all these losses. The evaporation of 2.7 gph will dissipate 7 kw of loss, or approximately the full load loss of 500 kva transformer and associated network protector. Fig. 3 shows, in full lines, the maximum quantity of water that could be evaporated in a transformer vault for various air temperature rises, assuming that 350 cfm of air are circulated through the vault; that the amount of air circulated varies with temperature rise; that the outlet air is completely saturated; and that the outside air temperature is 26 C. The air transfer rate of 350 cfm is the approximate amount of air circulated at continuous full load through a vault of the type shown in Fig. 1 with natural ventilation only. Values below 350 cfm are based on the air velocity being proportional to the square root of the air temperature rise which takes into account the "stack" effect.

The actual amount of moisture that will be evaporated within a vault for a particular temperature rise, kilowatt loss, and rate of air transfer depends upon the effectiveness of the nozzles used in providing a fine water spray, the location in the vault where the nozzles are placed, and the humidity of the inlet air. A considerably smaller quantity of moisture will be evaporated than shown in Fig. 3, which merely indicates maximum values.

Figure 4 is presented to show the relation, for a stated air temperature rise and rate of air circulation, between the losses which will be dissipated and the relative humidity of inlet and outlet air. The losses shown are the total losses removed by increase of the sensible heat content of the air plus the losses removed by moisture evaporation. Since the heat losses dissipated increase so markedly with evaporation, it is important to use nozzles which break up the moisture into as fine a mist as possible in order to facilitate the evaporation process. It is also important to locate the nozzles at points in the vault where a maximum of cooling may be obtained.

Figure 4 is plotted for a 12 C rise in air temperature which approximates the value found by test for continuous load conditions on the 500 kva installation shown in Fig. 1. The results of these tests are described in more detail in the next section.

While there is considerable advantage in the use of evaporative spray cooling in enclosed vaults, tests have not been made on units installed outdoors in free air; and it is difficult to predict the performance of such an installation since rapid free air movement would considerably affect the rate of evaporation.

A psychrometric chart is convenient for determining the quantities related to evaporative cooling and is the basis for the data presented in Figs. 3 and 4.

Test results

Tests have been made to determine the reduction in transformer, network protector, and air temperatures

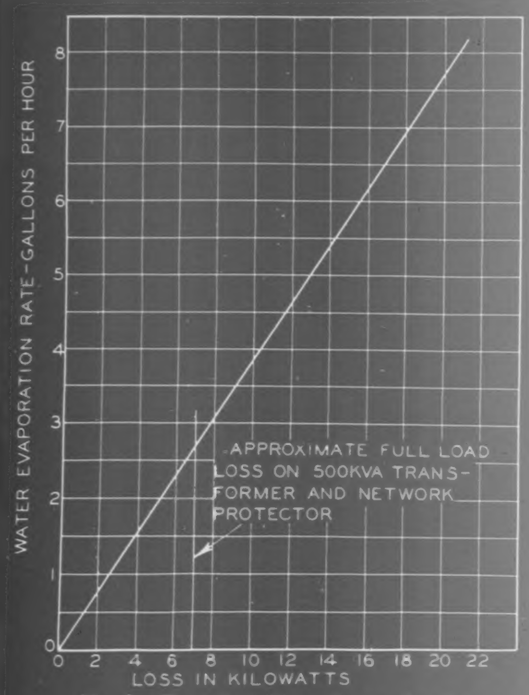


Fig. 2 — Theoretical Water Evaporation Rate vs. Kilowatts of Loss Removed by Evaporation.

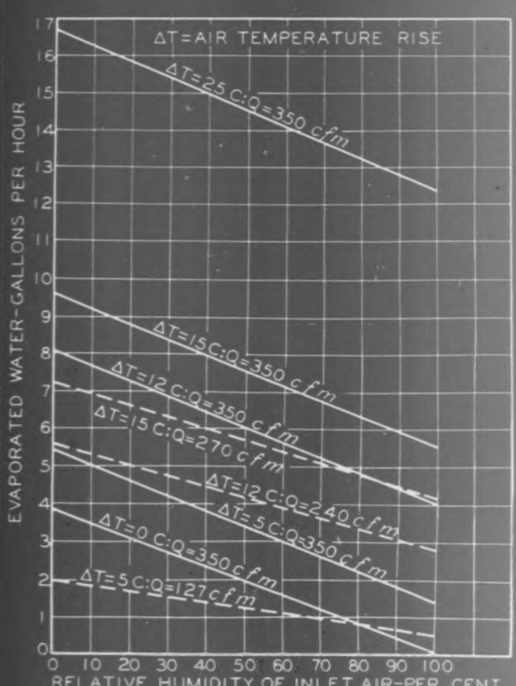


Fig. 3 — Maximum Evaporation of Moisture.

when evaporative spray cooling is used in a network transformer vault installation as compared with results when using natural ventilating facilities only. A typical 7 ft 4 in. by 6 ft 10 in. by 7 ft 4 in. transformer vault was installed in the ground, and a standard 27 kv, 500 kva vault type transformer and 1600 ampere vault type network protector were installed therein. Standard ventilation for this vault was provided by a 4 ft 0 in. by 4 ft 3 in. grating having a net opening of 10.5 sq ft. Fig. 1 shows the arrangement of equipment and of the spray nozzles and piping in this vault. The evaporative spray cooling installation was made with four misting nozzles in a ½ in. water pipe located at the top cooling tube level on the three sides of the transformer having cooling tubes with the nozzles directed toward the transformer tubes. The water supply was taken directly from the city water system at the existing pressure of 60 lb per sq in.

Transformer load was adjusted to suit test requirements for both continuous loading at 500 kva and cyclic loading. Cyclic loading consisted of an overnight sixteen hour period at 225 kva load followed by eight hours at 750 kva load.

Four groups of tests were conducted using evaporative cooling, and comparative tests were made with natural ventilation. The cooling effects for each group of spray cooling tests are listed in Table I. Fig. 5 shows comparative heating curves for two cyclic loading tests, each having 150 percent peak load. The lower heating curve on Fig. 5 indicates the oil temperature rise over outdoor ambient with spray cooling, and the upper curve indicates the oil temperature rise over outdoor ambient without water spray cooling. It is evident that considerable time is required for the full cooling effect of the water spray to be realized. This accounts for the lower reduction in temperature shown for the Group No. 3 tests in Table I as compared with the Group No. 1 tests.

Group No. 4 tests were conducted to determine the effectiveness of a short evaporative spray precooling period at the end of a peak load period for the purpose of starting the following day's load cycle with a reduced ambient temperature in the vault. Obviously this is far less effective than using the water spray during peak load periods.

No attempt was made to collect and measure the unevaporated quantity of water in these tests, but measurements were made of the water inlet temperature, outdoor temperature and humidity, and vault air temperature and humidity. The transformer oil temperature reduction with spray cooling is greater than calculations indicated although the air temperature reduction checks quite closely with calculated values. This is attributed to the fact that, with normal ventilation, a high temperature gradient probably exists between the tank wall and the air immediately surrounding the tank; whereas, with water spray cooling, this hot air film is partially eliminated with a resultant additional reduction in transformer tem-

Test Group Number	Load Cycle	Peak Load, kva	Number of Nozzles	Water		Usage	* Approximate Reduction in Temperature Resulting from Use of Water Spray Evaporative Cooling, °C.		
				Pressure, lb per sq in.	Rate, gph		Transformer Top Oil	Network Protector	Vault Ambient Air
1	Continuous	500	4	60	5.3	Continuous	25	8	13
2	Continuous	500	2	40	2.5	Continuous	† 8	No protector used	..
3	Cyclic	750	4	60	5.3	Above 69 C top oil temperature	‡15	Negligible	Approx 10
4	Cyclic	750	4	60	5.3	Four hour period at end of previous day's peak load	Negligible	Negligible	Negligible

TABLE I — Cooling Produced by Water Spray in a 500 Kva Transformer Vault Installation

* Below values existing under the same loading cycles but with natural ventilation only. Relative humidity of outside air approximately 60 percent.

† Adjusted for effect of removing network protection from the vault.

‡ Test continued for full eight hours at 150 percent load. Similar test without water had to be discontinued after approximately six hours at 150 percent load because of excessive temperature.

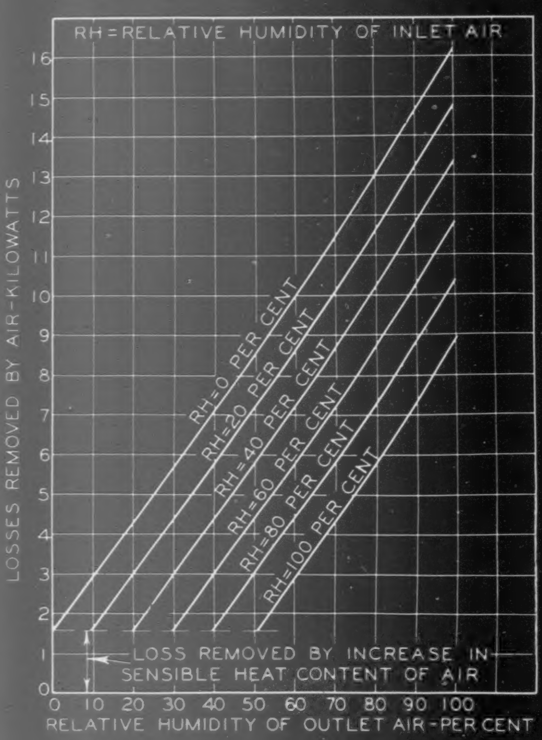


Fig. 4—Losses Removed by 240 Cfm of Air for 12C Rise in Air Temperature.

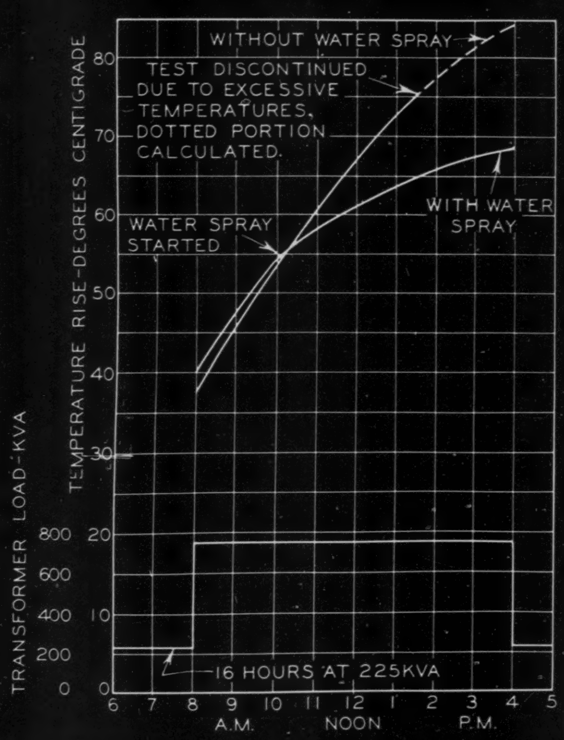


Fig. 5—Top Oil Temperature Rise of 500 Kva Transformer Over Outdoor Ambient Temperature.

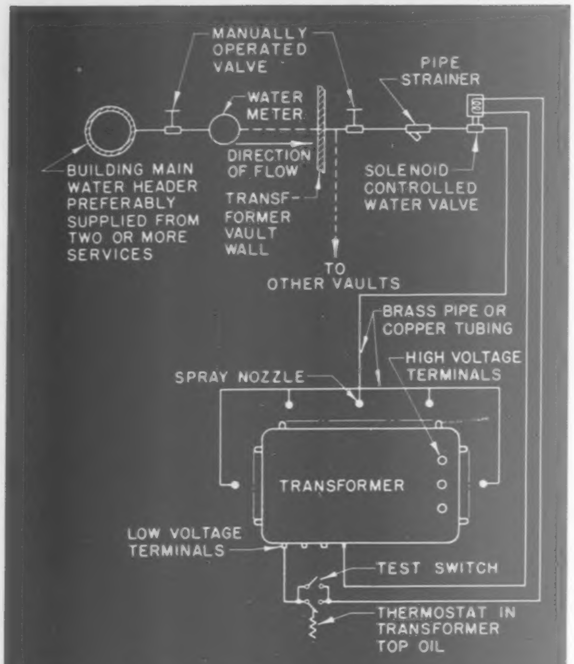


Fig. 6 — Schematic Diagram of Wiring and Water Piping for Water Spray Installation in Transformer Vault.

perature. This is indicated by the fact that the reduction in air temperature, brought about by the use of evaporative cooling during the continuous full load test, was in the order of 12 to 14 C, while the reduction in transformer oil temperature was about 25 C.

Test data indicated that about 30 percent of the water sprayed into the vault was actually evaporated when using four nozzles, but the use of less nozzles caused a decrease in the quantity of water evaporated and hence a decrease in permissible transformer loading.

Increased transformer rating

The improvement in transformer rating resulting from the use of water spray evaporative cooling in vault installations depends upon a number of factors, of which the most important are:

1. Thermal characteristics of the transformer.
2. Type of load cycle.
3. Temperature limits used for establishing transformer loading.
4. Outdoor air humidity.
5. Thermal characteristics of transformer vault.
6. Arrangement of spray nozzles with respect to the equipment in the vault.
7. Number and characteristic of water nozzles used.
8. Number of hours per day during which water spray is used.

A complete review of the effects of all of these variables is too lengthy for the present discussion. Calculations have been made, however, to show the effect of water spray cooling on transformer rating for the particular installation used in the test set-up of Fig. 1. The results are believed to be fairly representative of the improvement to be expected from any similar installation. Table II compares ratings with and without water spray for the same hot spot temperature, assuming an outdoor relative humidity of approximately 60 percent and an outdoor air temperature of 26 C.

Transformer Loading	Hot Spot Copper Temperature Limit in °C	Allowable Load—Kva		Approximate Increase in Rating Effected by Use of Water Spray in Percent
		Natural Ventilation Only	Natural Ventilation Plus Water Spray	
Continuous	95	460	590	28
	110	540	655	21
	125	605	715	18
Cyclic	105	600	675	13
	110	630	700	11
	125	715	785	10

TABLE II — Comparative Ratings With and Without Water Spray

The loading limits indicated above are for distribution transformers supplying a low voltage network. The 95 C and 105 C hot spot temperature limits are used for normal loading, which may be repeated daily when all high voltage feeders supplying the network are in service. First contingency loading, with a hot spot temperature of 110 C, is the loading which is permitted at times when one high tension feeder supplying the network area is out of service. Second contingency loading, with a hot spot temperature of 125 C, is the loading which is permitted for one eight hour peak load period when a total of two associated feeders are out of service, following a first contingency period. The 95 C and 105 C temperature limits shown above for normal operation are the limits proposed by the American Standards Association. Higher temperatures are permitted for first and second contingency operation than for normal operation since the number of these contingency conditions occurring per year are limited; hence the reduction in transformer insulation life is not excessive. First contingency occurs on the average about once per month, and second contingency occurs about once in eighteen months.

Loading data for continuous and block cyclic loading, having an eight hour peak period of the type shown on Fig. 5, are presented in the above tabulation since they are simpler to calculate and are the type of load cycles used during tests. Actual system load curves are frequently different from these although the block cyclic loading used approximates fairly closely the type of load found in certain office building and industrial areas.

Fig. 7 — Close-up View of Nozzle Arrangement.

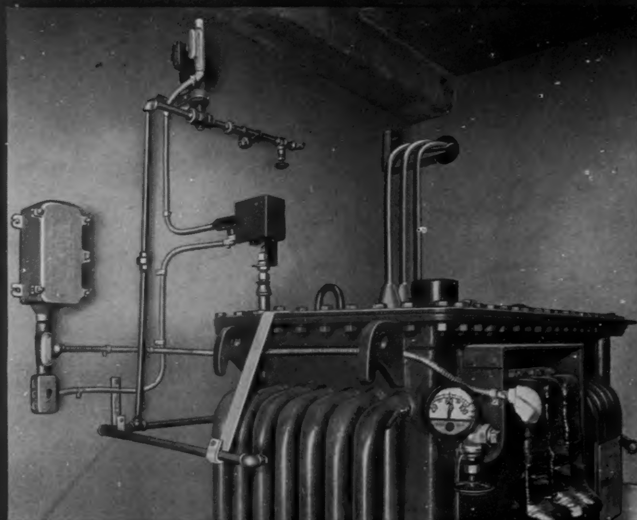


Fig. 8 — Installation of Network Transformer Equipped with Evaporative Spray Cooling.

Water supply, control, and usage

At vault installations where water spray cooling is provided, the water supply may be taken from the nearest point on the street mains or on the main header in the building adjacent to the vault and piped to the vault through ½ in. brass pipe or copper tubing.

Within the vault compartment, a manually operated valve is installed in the pipe line to provide means for shutting off the water during maintenance operations. A fine mesh screen, followed by a solenoid operated valve, is installed in the pipe line after the manual valve; and the solenoid valve operation is controlled by a thermostat whose actuating element is located in a "well" in the transformer oil about 5 in. below the top oil level. This thermostat may be set to open the solenoid valve at any desired oil temperature. A suggested setting is to open the valve when the top oil temperature reaches 70 C and close the valve when the top oil temperature is reduced to 65 C. The 120 volt supply for the operation of the solenoid valve may be taken from the transformer secondary terminals or the network protector, depending upon which is more convenient. Fig. 6 shows a schematic wiring diagram of the control circuit for a water spray installation and a schematic diagram of the water piping.

It will be noted that there are five nozzles indicated on Fig. 6, whereas only four were used during tests. The extra nozzle is intended for use at actual system installations in order to improve the cooling further.

By automatic control of the water based on temperature, a maximum use is made of the natural ventilating facilities; most economic use is made of the water; use of the water is insured during periods when conditions require its use; and no water is used when it is not required. These are the advantages of automatic control compared to manual operation, whereby the water would be turned on when feeder contingencies were known to exist.

The estimated water usage for a 500 kva installation of the automatic type described above should not exceed 4,000 gallons per year.

Trial installation

A few actual system installations are being made to provide experience with evaporative spray cooling and to determine the effect of the humid atmosphere on transformer maintenance from the standpoint of paint and gasket life. Figs. 7 and 8 show details of actual system installation. The additional maintenance required for such installations should not be excessive. It will be necessary to clean the strainers in the water line and in the nozzles about once a year. It may be necessary to check the thermostat and solenoid valve operation at definite intervals to insure correct operation.

THE GAS TURBINE
II. THERMODYNAMIC CONSIDERATIONS*

From many different earlier designs has recently emerged the modern combustion gas turbine. Here enlightening charts aid technical equations in explaining its principles of operation.

Dr. J. T. Rettaliata

STEAM TURBINE DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

● Notwithstanding the many different types of gas turbines proposed during their long experimental period, the vast majority of these units were intended to operate on either the constant volume or the constant pressure cycle.

Gas turbines of the explosion type, the most notable being the Holzwarth units, operate on the constant volume cycle, similar to that shown on the pressure-volume plane in Fig. 18. Precompression of the charge is represented by AB. Explosion at constant volume is shown by BC, and expansion in the turbine by CD. The theoretical work of the cycle is indicated by area ABCD.

The preceding brief reference to the constant volume cycle has been presented in order to distinguish it from the constant pressure cycle, which has attained much more commercial significance because of its use in the combustion gas turbine.

The constant pressure, or Brayton, cycle on which the combustion turbine operates, consists of two isentropic and two isobaric state changes, as shown theoretically on the pressure-volume plane in Fig. 19. Line AB represents the isentropic compression of the air in the compressor. The isobaric addition of heat to the mixture of air and gas in the combustion chamber is depicted by BC. The isentropic expansion of the gas in the turbine is portrayed by CD. Completion of the cycle is accomplished by the assumed isobaric removal of heat from the exhaust gas along DA.

In a steady flow reversible process, area FBAE represents the amount of energy theoretically required

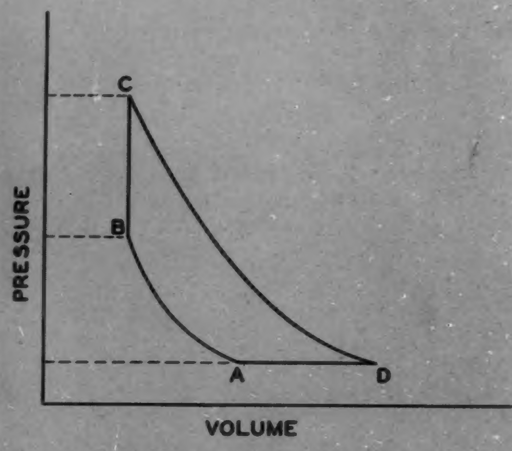


Fig. 18—Explosion Turbine Cycle.

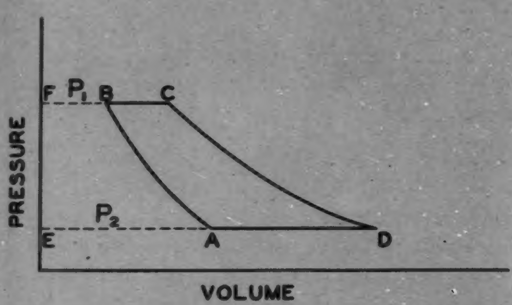


Fig. 19—Combustion Turbine Cycle.

* The second of three definitive articles by Dr. Rettaliata on the history and modern status of the combustion gas turbine. Part I appeared in Sept., 1941, issue, and Part III will run in the March, 1942, issue of Allis-Chalmers ELECTRICAL REVIEW.

AT LEFT: Rolled steel yokes for several sizes of large direct current machines are inspected before machining.

to compress one pound of air in the compressor, while the theoretical energy created by the expansion of one pound of gas in the turbine is shown by area FCDE. Therefore, the difference between these two areas, ABCD, would represent the theoretical excess energy available for power purposes per pound of fluid. Since introduction of fuel into the cycle occurs after compression of the air, correction must be made when determining excess power for the slightly greater quantity and different composition of the fluid undergoing expansion than that being compressed. While not exactly negligible, these corrections are small, for the amount of fuel used will be less than one percent of the weight of the air compressed when the turbine inlet temperature is 1000 F with a pressure ratio of four.

Mathematical expression for excess energy

Area FBAE, representing the compressive energy per pound of fluid, may be expressed mathematically as

$$FBAE = \int_{P_2}^{P_1} V_{AB}\, dP \qquad (1)$$

Similarly, area FCDE, equivalent to the expansive energy, may be written

$$FCDE = \int_{P_2}^{P_1} V_{CD}\, dP \qquad (2)$$

Therefore, area ABCD, signifying the excess or useful energy available for power purposes, may be indicated by

$$ABCD = \int_{P_2}^{P_1} V_{CD}\, dP - \int_{P_2}^{P_1} V_{AB}\, dP \qquad (3)$$

Using the perfect gas relationship

$$PV^k = \text{const.} \qquad (4)$$

to represent an isentropic state change, equation (3), upon integration and substitution of limits, becomes, in units of Btu per pound,

$$\Delta h_{ABCD} = \frac{144}{778}\,\frac{k}{k\text{-}1}\,P_1\,(V_C - V_B)\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}\right] \qquad (5)$$

where: k = isentropic exponent, i. e., ratio of specific heats, of fluid in cycle;

P_1 = pressure at turbine inlet and compressor discharge, psi, abs;

P_2 = pressure at turbine exhaust and compressor intake, psi, abs;

V_C and V_B = specific volumes, at turbine inlet and compressor discharge, respectively, cu ft per lb.

As mentioned previously, when ascertaining the true theoretical excess energy of a cycle, correction must be made for the quantity of fuel consumed. Therefore, equation (5), after being modified to account for the addition of fuel, becomes

$$\Delta h_{ABCD} = \frac{144}{778}\,\frac{k}{k\text{-}1}\,P_1\left[(1+x)\,V_C - V_B\right]\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}\right] \qquad (6)$$

where: x = pounds of fuel used per pound of air discharged from the compressor.

By substituting in equation (6) appropriate values for a particular cycle in question, the theoretical excess energy per pound of air compressed may be determined. The use of equation (6), however, assumes the fluids in the compressor and turbine to have the same specific heats, which is not the case since they

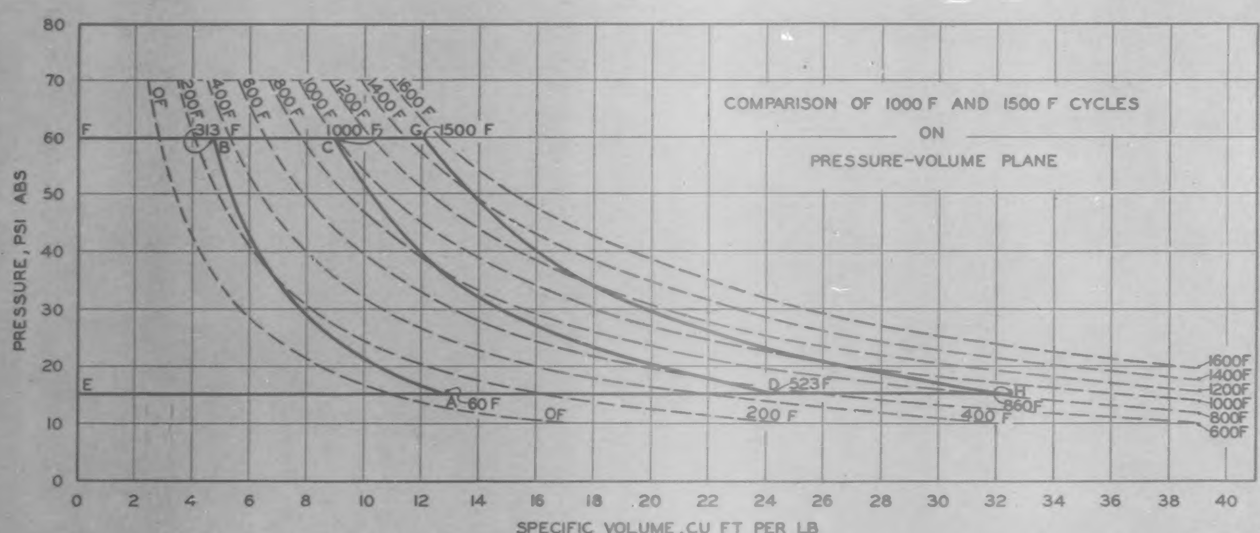


Fig. 20 — Effect of Inlet Temperature on Theoretical Energy Available for Power.

vary with temperature; and allowance will be made for such variation in the following section.

Effect of turbine inlet temperature on excess energy developed

The maximum design temperature of the present combustion gas turbine units is 1000 F at the turbine inlet. This temperature has been adopted as a safe operating limit with the materials of construction employed. Because the potentialities of the gas turbine appear much more attractive at elevated temperatures, it is evident that research on metals capable of withstanding higher temperatures will have a predominant influence on its future. Laboratory metallurgical investigations now in progress indicate that continuous operation at 1500 F is within the realm of possibility. Preliminary results reveal materials exhibiting satisfactory rates of creep at elevated temperatures when subjected to stresses likely to be encountered in normal design practice.

As a means of demonstrating the effect of turbine inlet temperature on the theoretical energy per pound of fluid available for power purposes, reference is made to Fig. 20, wherein two cycles, operating at respective temperatures of 1000 F and 1500 F, are depicted on a pressure-volume plane. A pressure ratio of four has been used, making the upper pressure level 60.0 psi, abs when an assumed pressure of 15.0 psi, abs prevails at the lower level of the cycle. The temperature of the air entering the compressor has been taken as 60 F. Isotherms have been superimposed on the diagram so that the temperature of the fluid medium in any part of the cycle may be readily ascertained.

Since the compressive, or negative, work of the cycle is constant because of the fixed location of the compression line AB, observation shows that the area representing excess energy will be greater with the 1500 F gas, expanding according to line GH, than with the 1000 F gas, whose expansion is portrayed by line CD.

The magnitude of the exact difference in excess energy between the two cycles may be determined by employing the perfect gas relationship

$$144\ PV=RT \quad\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

in revising equation (6) into the form

$$\Delta h_{ABCD}=\frac{1}{778}\,\frac{k}{k-1}\,R\left[(1+x)\,T_C-T_B\right]\left[1-\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}\right] \quad (8)$$

where: R=gas constant;

T_C and T_B=temperature at turbine inlet and compressor discharge, respectively, deg F, abs.

The energy required for compression being constant, equation (8) may be written

$$\Delta h_{ABCD}=c_1\,(1+x)\,T_C-c_2 \quad\ldots\ldots\ldots(9)$$

and, neglecting the variation in the amount of fuel added for different turbine inlet temperatures,

$$\Delta h_{ABCD}=c_3\,T_C-c_2 \quad\ldots\ldots\ldots\ldots\ldots(10)$$

where: c_1, c_2, c_3=constants.

Therefore, for a fixed compression ratio and isentropic exponent, the excess energy varies approximately as the absolute temperature of the fluid entering the turbine minus a constant equivalent to the energy necessary to accomplish compression.

After making suitable modifications for variation in specific heats, equation (8) may be employed in calculating the difference between the theoretical excess energies of the cycles shown in Fig. 20.

Another and more convenient method for determining the excess energy of a cycle is afforded by the use of the combined temperature-entropy and enthalpy-entropy diagram for air shown in Fig. 21.

This chart, based on the Partington and Shilling[8] equations for variable molar specific heats, takes into account the change in isentropic exponent occurring in the cycle. Its use assumes the fluid throughout the entire cycle to have the same properties as air. Because of the small amount of fuel actually injected, such an assumption may be considered essentially correct for all practical purposes.

Construction of the chart utilizes perfect gas relationships for changes in entropy. The variation in entropy accompanying an isothermal state change is given by

$$\Delta S=\frac{R}{778}\,\log_e\frac{P_1}{P_2} \quad\ldots\ldots\ldots\ldots\ldots(11)$$

and that occurring during an isobaric state change may be obtained from

$$\Delta S=\int_{T_1}^{T_2} c_p\,\frac{dT}{T} \quad\ldots\ldots\ldots\ldots\ldots\ldots(12)$$

where: ΔS=difference in entropy between the initial and final points of the path of the state change, Btu per lb F;

c_p=instantaneous specific heat at constant pressure, Btu per deg F per lb.

After substitution for c_p, the instantaneous specific heat relation

$$c_p=a+bT+cT^2,$$

equation (12), upon integration between temperature limits of T_1 and T_2, becomes

$$\Delta S=a\,\log_e\frac{T_2}{T_1}+b\,(T_2-T_1)+\frac{c}{2}\,(T_2^2-T_1^2) \quad\ldots(13)$$

in which, from Partington and Shilling,

[8] J. R. Partington and W. G. Shilling, "The Specific Heat of Gases," D. Van Nostrand Co., Inc., New York, N. Y., 1924.

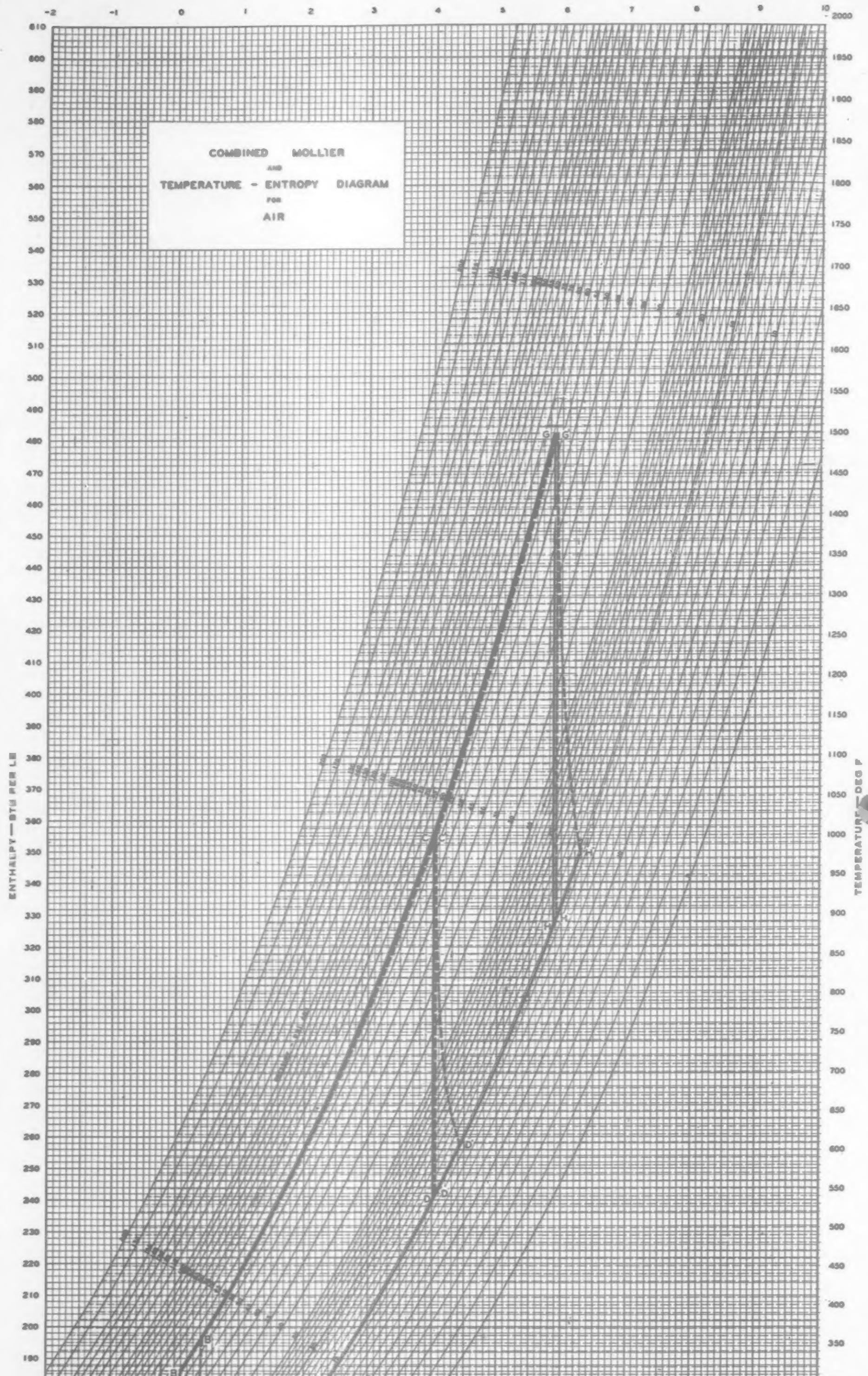


Fig. 21—Combined temperature-entropy and temperature-enthalpy diagram for air.

$$a = \frac{6.914}{m}$$

$$b = \frac{9.5 \times 10^{-5}}{m}$$

$$c = \frac{9.6 \times 10^{-8}}{m}$$

where: m = molecular weight of air.

The enthalpy scale on the diagram in Fig. 21 is obtained from the relation

$$h = \int_0^T c_p \, dT \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

After substituting for c_p and integrating, equation (14) becomes

$$h = a\,T + \frac{bT^2}{2} + \frac{cT^3}{3} \ldots\ldots\ldots\ldots (15)$$

where: h = enthalpy above absolute zero, Btu per lb.

The same two theoretical cycles shown on the pressure-volume plane in Fig. 20 are reproduced with similar nomenclature on the temperature-entropy and enthalpy-entropy diagram in Fig. 21. In addition, actual cycles, incorporating the internal losses encountered in operation, are indicated by the broken lines. Such operating losses comprise the pressure drop occurring between the compressor discharge and turbine inlet and the reheating effect produced in the compressor and turbine, which increases the entropy of the terminal points of the state changes and thereby reduces the excess energy of the cycle.

The theoretical 1000 F cycle is shown in Fig. 21 by ABCD. The energy required for isentropic compression of the air is equivalent to the difference in enthalpy between B and A. Thus, compressive energy may be expressed as

$$\begin{aligned} \Delta h_{AB} &= h_B - h_A \\ &= 185.2 - 124.6 \\ &= 60.6 \text{ Btu per lb.} \end{aligned}$$

Similarly, the energy liberated by the gas expanding in the turbine is equivalent to

$$\begin{aligned} \Delta h_{CD} &= h_C - h_D \\ &= 355.0 - 240.0 \\ &= 115.0 \text{ Btu per lb.} \end{aligned}$$

Therefore, the theoretical excess energy per pound of air compressed is

$$\Delta h_{ABCD} = (1 + x)\, \Delta h_{CD} - \Delta h_{AB}.$$

For a turbine inlet temperature of 1000 F the value of x will be approximately 0.0096 pounds of oil per pound of air compressed, when using oil having a lower heating value of 17,700 Btu per pound.

Therefore,

$$\begin{aligned} \Delta h_{ABCD} &= (1 + 0.0096)\,(115.0) - 60.6 \\ &= 55.5 \text{ Btu per lb of air compressed.} \end{aligned}$$

The theoretical excess power then is equivalent to

$$\begin{aligned} \Delta P_{ABCD} &= \frac{\Delta h_{ABCD}}{2545} \\ &= 0.0218 \text{ hp per lb of air per hr.} \end{aligned}$$

By a similar procedure it can be shown that the excess energy, Δh_{ABGH}, for the theoretical 1500 F cycle is 97.9 Btu per pound of air compressed, which is 76 percent greater than for the 1000 F cycle.

For the actual cycle represented by AB′C′D″ in Fig. 21, compressor and turbine internal efficiencies of 84 and 86 percent, respectively, have been assumed. The actual state changes, therefore, will be polytropic instead of isentropic. Compression will be in accordance with line AB′ instead of AB, and the actual compressive energy will be

$$\begin{aligned} \Delta h_{AB'} &= \Delta h_{AB} \div 0.84 \\ &= 72.2 \text{ Btu per lb.} \end{aligned}$$

The end point B′ will have an enthalpy of

$$\begin{aligned} h_{B'} &= h_A + 72.2 \\ &= 196.8 \text{ Btu per lb.} \end{aligned}$$

The discharge temperature of the air at B′ will be 356 F instead of 320 F, which it was after isentropic compression.

A one pound pressure drop has been assumed to exist between the compressor discharge and the turbine inlet, thus locating the point C′ at 1000 F and 57.8 psi, abs.

The effective heat drop through the turbine will be

$$\begin{aligned} \Delta h_{C'D''} &= \Delta h_{C'D'} \times 0.86 \\ &= (h_{C'} - h_{D'}) \times 0.86 \\ &= (355.0 - 241.2) \times 0.86 \\ &= 97.9 \text{ Btu per lb.} \end{aligned}$$

The enthalpy of the actual end point of the expansion D″ will be

$$\begin{aligned} h_{D''} &= h_{C'} - 97.9 \\ &= 257.1 \text{ Btu per lb.} \end{aligned}$$

The actual terminal temperature of the exhaust gas at the end of expansion will be 605 F, which is higher than in the case of isentropic expansion, when its temperature was 540 F.

Deducting one-half of one percent for mechanical losses, gland leakage, and radiation, actual excess energy for the 1000 F cycle will be

$$\begin{aligned} \Delta h_{AB'C'D''} &= \left[0.995\,(1+x)\,\Delta h_{C'D''} - \frac{\Delta h_{AB'}}{0.995}\right] \\ &= \left[0.995\,(1+0.009)\,(97.9) - \frac{72.2}{0.995}\right] \\ &= 25.7 \text{ Btu per lb of air compressed.} \end{aligned}$$

It will be noted that slightly less fuel has been used because the temperature of the air discharged

from the compressor is higher than in the theoretical cycle.

The actual excess power is

$$\Delta P_{AB'C'D''} = \frac{\Delta h_{AB'C'D''}}{2545}$$

$$= 0.0101 \text{ hp per lb of air per hr.}$$

Similarly, for the 1500 F cycle the actual excess energy, $\Delta h_{AB'G'H''}$ is 61.4 Btu per pound of air compressed, which is 139 percent greater than for the actual 1000 F cycle.

From the foregoing it can be seen that the difference between the 1500 F and 1000 F cycles is much more pronounced when comparing actual cycles than when comparing theoretical cycles.

As in the case of the pressure-volume diagram of Fig. 20, observation of Fig. 21 will also reveal that the excess energy for the 1500 F cycle will be greater than for the 1000 F cycle because of the divergence of the pressure lines with increasing entropy.

Based on calculations similar to the above, Fig. 22 has been constructed showing theoretical and actual outputs per pound of air as a function of turbine inlet temperature.

The ordinate scale expresses output per pound of air in terms of actual output at 1000 F and operating under the same conditions as assumed in the foregoing calculations. The 1000 F operation has been designated as normal and selected as a basis for comparison since it is indicative of what is possible of attainment with materials in use at the present time.

From the curve depicting actual output it will be noted that, at an inlet temperature of approximately 635 F, the power delivered by the turbine will exactly balance that required by the compressor. Therefore, to produce excess energy, it is necessary to operate at temperatures greater than this value.

With an inlet temperature of 1000 F the curves indicate that only about 45 percent of the theoretical excess energy is actually realized in useful work. Improvement comes with higher temperatures, however, for at 1500 F about 63 percent of the theoretical excess energy is utilized. Manifestly, high turbine and compressor efficiencies as well as minimum pressure drops throughout the system are desiderata, the attainment of which is imperative in the interest of increasing the energy utilization factor.

Figure 22 adequately reveals the benefits to be obtained from operating at higher temperatures and affords an incentive for continued research in quest of materials to withstand such temperatures. Reference to the figure indicates that operation at 1500 F would produce approximately two and one-half times as much energy per pound of fluid as is obtainable with a temperature of 1000 F.

The effect of intake-air temperature on the power delivered by a unit is shown in Fig. 23. As may be seen from the curve, an increase in temperature decreases materially the output of a given unit. On the other hand, a unit designed for normal operation with an intake-air temperature of 60 F will develop approximately 50 percent more than rated power when the air temperature is reduced to 0 F.

The output of a unit as affected by altitude is illustrated by the curve in Fig. 24. Upon examination it can be seen that high altitudes have an adverse effect on the power obtainable.

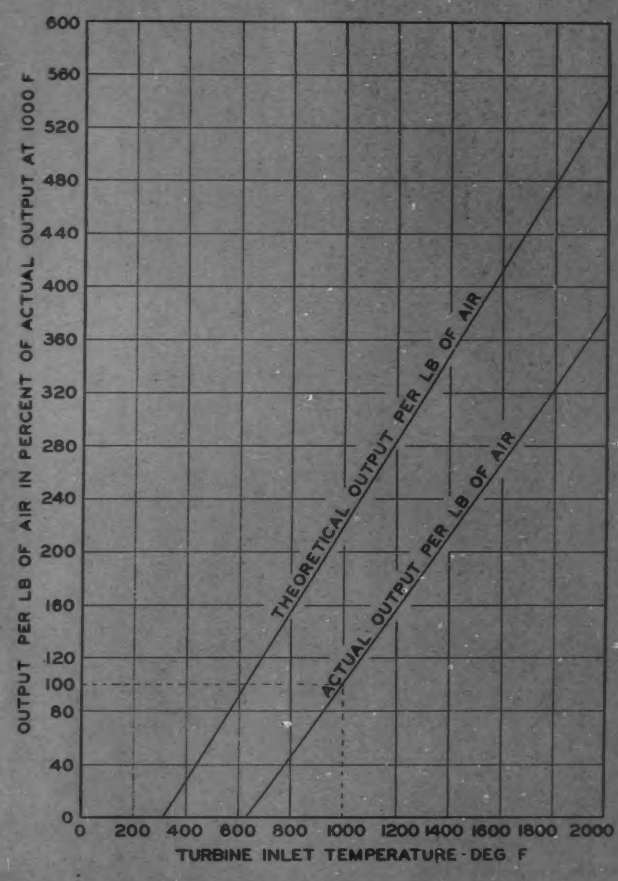


Fig. 22 — Theoretical and Actual Outputs Per Lb of Air as a Function of Turbine Inlet Temperature.

AT LEFT: Welding the stator yoke of a synchronous generator. If it were still necessary to make castings of the myriad of structural shapes now welded, industry would be even more hard-pressed to meet the growing load of defense.

If the unfavorable effect of temperature and altitude is of a temporary nature, as may be the case, for instance, in locomotive or marine applications, it may be remedied by water injection; for, by reason of its molecular weight and isentropic exponent (when in superheated vapor state) being less than that of air, water injected into the combustion chamber will increase the excess power developed by a given size of gas-turbine axial-compressor unit. Such a procedure, while augmenting the output of the unit, is nevertheless an inefficient practice owing to the latent-heat-of-vaporization loss at the turbine exhaust. If indulged in extensively, the reduction in over-all thermal efficiency may prove prohibitive.

Additional natural concomitants of operation at elevated temperatures are decreased weight and cost per unit output, as well as increased thermal efficiency; the latter is to be dealt with in the third article of this series.

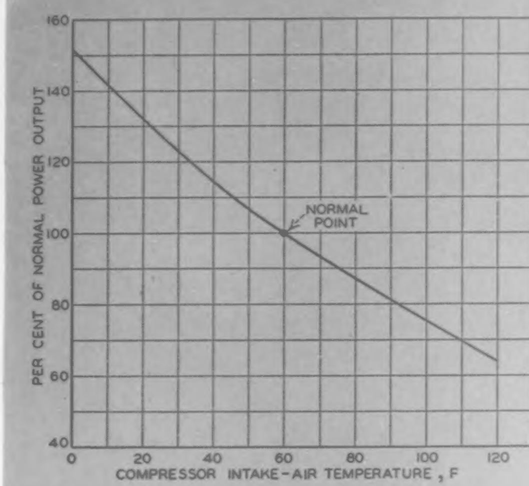


Fig. 23 — Effect of Intake-Air Temperature on Excess Power.

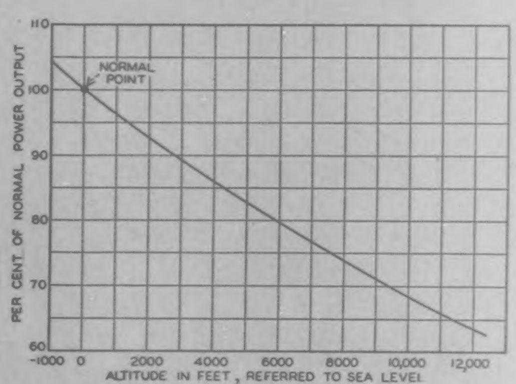
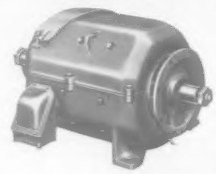


Fig. 24 — Effect of Altitude on Excess Power.

Water-Proof Motor

For driving above-deck anchor winches, cargo hoists, and capstans, a new waterproof d-c motor is available which meets the specifications of the American Bureau of Shipping, A. I. E. E., and Bureau of Marine Inspection and Navigation. Accurately machined joints and extra bearing seals make possible waterproof construction without the use of gaskets. Access to the brushes is provided by a large handhole covered with a steel plate.



The top half of the yoke can be unbolted and simply lifted off because all the interpoles are located in the lower half of the frame. Special marine type insulation is used, and the windings are carefully impregnated.

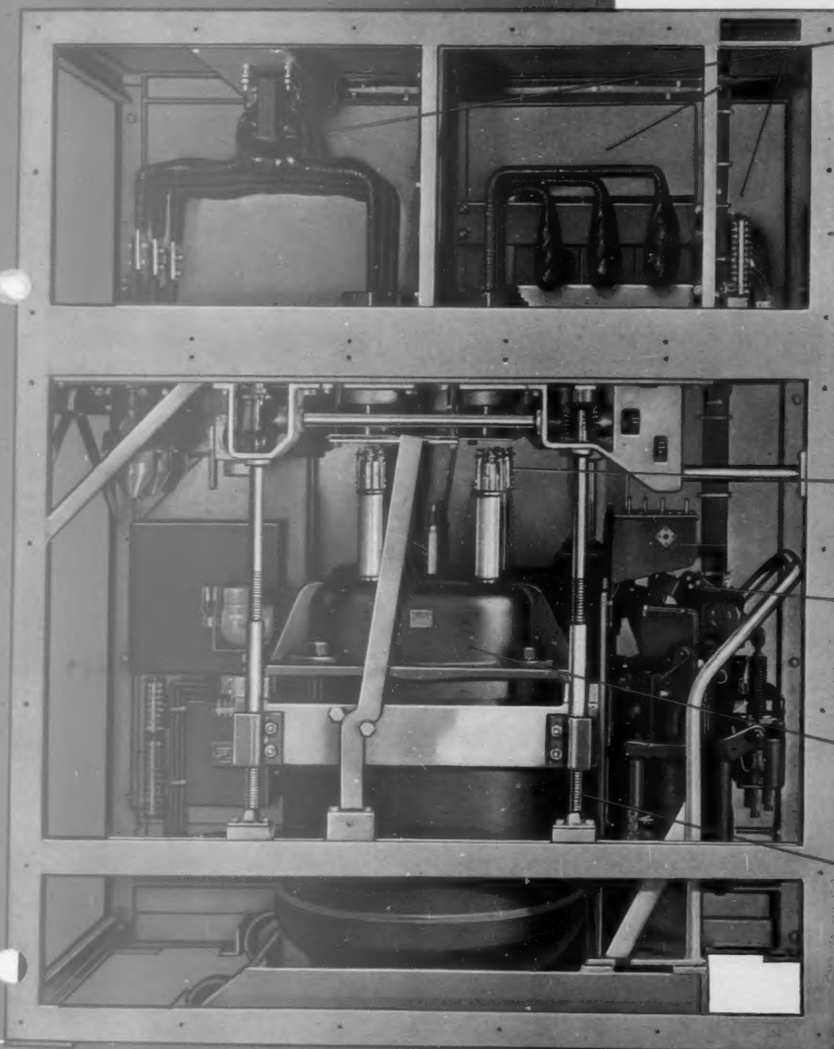
Ratings available are from 25 to 100 hp, 310 to 675 rpm, but not all ratings are available at all speeds. Development work is now taking place on additional ratings to permit the use of this motor for a greater variety of special applications.

Service Elevator for Power Plants

Hidden until recently in flour mills and parking garages was an elevator that is now proving to be an important personnel carrier in power plants. The Service Elevator or "Man Lift" consists of a wide flat-belt running over pulleys located in the basement and above the top floor of the plant. Wide steps and handholds are provided at two second intervals, and on one side of the belt the operator can ride up and on the other side ride down. Safety limit switches protect the operator from injury if he fails to get off at the top floor. Rope controls running the full length of the elevator permit starting or stopping at any point.

One superintendent of an eastern utility stated that the service elevator could save its purchase price in one emergency by enabling an operator to get to the top of the boiler in a hurry.

For further, more detailed information regarding these new products, write the Editors of ELECTRICAL REVIEW.



How to get Narrow Band Widths with only 1/3 THE EXCITING CURRENT!

Allis-Chalmers 5/8% Step DFR Regulators Maintain Narrower Band Widths . . . Require 67% Less Wattless Current! Here is One Way You Can Save the Cost of Static Capacitors . . . Release System Capacity for Pay Loads!

You don't have to burden your system with extra wattless current to get narrow band widths.

For the Allis-Chalmers 5/8% Step Regulator holds narrow band widths — as low as ±3/4 volts for some feeders — and does it with *only 1/3 the excitation current required by older types of regulators!*

Let's take a typical case. A public utility needs ten 72 kva, 2400 volt regulators. Their chief engineer finds that he can free his lines of 122 reactive kva if he installs Allis-Chalmers DFRs rather than older type regulators.

That's a total saving of $850 on static capacitors alone* — actually 4% of the regulators' cost! But even if static capacitors aren't used, 55 kva of system capacity will still be released (with 90% power factor loads).

Figure out what savings like this can mean on your lines! And don't forget DFR's narrower band widths . . . reduced losses . . . quieter operation . . . minimum maintenance costs!

Bulletin B-6065 gives complete information on Allis-Chalmers 5/8% Step DFR Regulators. Write for your copy . . . *today!*

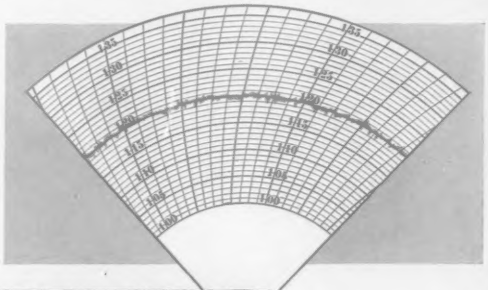
*Average installed cost—$7 per kva.

A 1402

5/8% Step Regulators Have Been Holding 2 VOLT BANDS FOR 7 YEARS!

When the Allis-Chalmers 5/8% Step Regulator was designed over eight years ago, the size of steps was selected as 5/8 of 1% because data gathered from utilities all over the country indicated that the 2 volt band was desirable.

Look at the accompanying chart, a typical record obtained under actual service of an Allis-Chalmers DFR. It shows how the voltage is easily held within a 2 volt band.



Northwestern system likes the lower excitation current and closer band widths provided by these six 72 kva, 2400 volt Allis-Chalmers 5/8% Step DFR Regulators.

These 5/8% Step Regulators Are Famous for Better Regulation at Lower Cost! Choose the Regulator to Fit Your Purpose!

DFR — 12 to 250 kva, single phase
AFR — 20.8 to 750 kva, three phase
CFR (air cooled) — 36-96 kva, 2400 volt, single phase

ALLIS-CHALMERS

MILWAUKEE · WISCONSIN